DOCUMENT RESUME

ED 472 523 SE 066 727

TITLE	GLOBE Program Teacher's Guide.
PUB DATE	1997-00-00
NOTE	849p.; Produced by Globe Program.
AVAILABLE FROM	GLOBE Program, 744 Jackson Place, Washington, DC 20503. Web site: http://www.globe.gov.
PUB TYPE	Guides - Classroom - Teacher (052)
EDRS PRICE	EDRS Price MF05/PC34 Plus Postage.
DESCRIPTORS	Academic Achievement; Biology; *Educational Technology; Elementary Secondary Education; *Environmental Education; Hands on Science; Hydrology; *Science Activities; Science Instruction; Soil Science; *Thinking Skills; *World Wide Web

ABSTRACT

The GLOBE Program is a worldwide, hands-on educational program for elementary and secondary school students. GLOBE aims to increase student achievement in mathematics and science, awareness towards the environment, and improve science process skills through network technology. This teacher's guide provides an overview of the GLOBE program and step-by-step guidance for teachers on the implementation of the program in schools and investigations. Contents include: (1) "Introduction"; (2) "Implementation Guide"; (3) "Atmosphere Investigation"; (4) "Hydrology Investigation"; (5) "Soil Investigation"; (6) "Land Cover/Biology Investigation"; (7) "GPS Investigation"; (8) "Season Investigation"; and (9) "Toolkit". Each investigation section includes an introduction, protocols, learning activities, and an appendix. Work and data sheets are provided. (YDS)

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GLOBE Program™ Teacher's Guide

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THE ***GLOBE*** PROGRAM™
744 Jackson Place, Washington, DC 20503 USA

Dear GLOBE Students:

You are about to begin an exciting adventure with students all over the world that will help all of us learn more about our planet! As participants in the *Global Learning and Observations to Benefit the Environment* (GLOBE) Program, you will collect environmental data in your school yard and neighborhood and you will share your findings with scientists and other GLOBE students.

Scientists have long been conducting research about the Earth's environment to understand how if forms a single, integrated system. However, scientists cannot take the Earth into a laboratory to study it. Instead, they must collect environmental data from all over the world continuously. Orbiting satellites collect much data about our planet, but people on the ground are needed to provide more detailed information. This is why you are an important member of the GLOBE Team.

As a GLOBE student scientist, you will assist scientists by taking careful measurements in the area around your school and reporting your data through the Internet. Your studies will include monitoring the air, water, soil, and vegetation. Each day you will be able to chart what is going on in the environment at your school, to compare your findings with data from thousands of other schools around the world and to have your data used to create pictures of the world environment based on GLOBE student data. You will be using your school computer to communicate with other GLOBE students involved in these same activities.

Scientists will be using your data to answer questions about our environment, and your data will continue to be useful ten, twenty, and even one hundred years from now! This is an historic opportunity for you to make a difference in your community and in our world. Scientists are anxiously awaiting your data...so let's get started!

Sincerely

Thomas N. Pyke, Jr.
Director

Visit the GLOBE Home Page at http//:www.globe.gov
For information or assistance, call toll-free in the U.S. 1-800-858-9947 or e-mail info@globe.gov or help@globe.gov

Global Learning and Observations to Benefit the Environment
An International Environmental Education and Science Partnership

THE **GLOBE** PROGRAM™
744 Jackson Place, Washington, DC 20503 USA

Dear GLOBE Teacher:

Congratulations on joining a worldwide network of teachers, students, and scientists working together to learn more about our environment! Because of your leadership, your students have the opportunity to work with GLOBE scientists and other GLOBE students around the world in exciting and serious study that will generate new knowledge about our planet.

GLOBE is a bold adventure for teachers and students. GLOBE enables you to engage your class in a collaborative, inquiry-based learning experience. Your students will have opportunity to explore the corners of the world and the crevices of their own school yard. GLOBE will also enhance your efforts to integrate state-of-the-art technology into your everyday class activities.

This GLOBE Teacher's Guide provides important information from the GLOBE scientists and educators which outlines the student measurement procedures and data quality techniques. We need your help to ensure that students recognize the importance of their work to the science community and that they appreciate the need to follow the measurement procedures carefully.

We have also included a wide variety of Learning Activities that you may choose to integrate into your lesson plans. These activities build on the GLOBE measurement activities and help students understand the "why" and "how" of their work.

We look forward to working with you to keep GLOBE meaningful for both you and your students. If you have any questions or ideas, please contact the GLOBE Help Desk at 1-800-858-9947 or send email to: help@globe.gov.

Sincerely,

Thomas N. Pyke, Jr.
Director

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Global Learning and Observations to Benefit the Environment
An International Environmental Education and Science Partnership

The GLOBE Program Overview

Global Learning and Observations to Benefit the Environment (GLOBE) is a hands-on international environmental science and education program. GLOBE links students, teachers, and the scientific research community in an effort to learn more about our environment through student data collection and observation.

The goals of GLOBE are:

- to enhance the environmental awareness of individuals throughout the world;
- to contribute to scientific understanding of the Earth; and
- to help all students reach higher levels of achievement in science and mathematics.

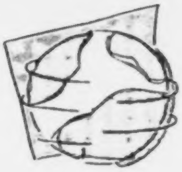
Students from the ages of approximately five through eighteen years in schools throughout the world conduct a continuing program of scientifically meaningful environmental measurements. GLOBE students transmit their data to a central data processing facility via the Internet, receive vivid images composed of their data and data from other GLOBE schools around the world, acquire information from a variety of sources, and collaborate with scientists and other GLOBE students and communities worldwide in using these data for education and research.

The measurements taken by the GLOBE students serve two important purposes. First, participating scientists use these data in their research programs to improve our understanding of the global environment. Second, students not only learn how to carry out a scientifically rigorous program of Earth observations, but also learn to use their own measurements, together with data from other GLOBE schools, as a key part of their study of environmental science. Through contact with and mentoring by scientists, the students receive feedback about the value of their data sets in world class scientific research.

GLOBE provides extensive educational materials to enrich the learning experience of participating students. These materials include a wide variety of classroom and field activities to help students place their measurements in a broader context and relate their own local observations to global environmental issues.

Using state-of-the-art technology, GLOBE creates a forum for students to communicate with their peers around the world, thus fostering alliances among students and increasing not only their environmental understanding but also their understanding of other cultures and their sense of global community.

GLOBE Science and Education



The GLOBE Program is both an international environmental science research program and an environmental science education program which, by design, includes a tight coupling between the two. This design was a result of a series of workshops that brought together international representatives of the science and education communities. There was agreement from both groups that science and education in the GLOBE Program should be mutually reinforcing.

The balance between science and education is reflected in the Teacher's Guide. The GLOBE science and education processes are represented in the scientific protocols and the educational learning activities. The implementation of this perspective has required involvement of both scientists and educators. Thus, peer-reviewed competitions are conducted to select Scientist Principal Investigator and Educator Co-Principal Investigator teams to develop GLOBE scientific and supporting educational materials and to select Educator Principal Investigators and Scientist Co-Principal Investigator teams to develop educational materials and provide evaluations and assessment tools.

These teams have designed measurement protocols that are appropriate for primary and secondary school students and that ensure accurate and reliable measurements for use by the international environmental science community. The GLOBE scientists will employ the GLOBE student measurement data in peer-reviewed publications and promote the use of these data to their colleagues. GLOBE is a hands-on, minds-on effort in which students will become the environmental experts for their study sites. GLOBE students do not just learn about science, they do science.

The GLOBE Program fosters the creation of a worldwide research team, comprised of students and teachers in collaboration with environmental scientists for the purpose of generating knowledge about the Earth as an interconnected system. In a similar manner, this team collaborates in facilitating the learning of science by students worldwide.

GLOBE learning activities are designed to promote the understanding of science through the use of tools such as visualizations and satellite images. Most GLOBE schools are able to communicate with one another through GLOBEMail, and some have used this capability to establish multi-country teams to initiate environmental science research projects. The activities of the teachers and students are strengthened by interaction with members of the science community.

Evolution of the GLOBE Program

As the GLOBE Program has evolved, it has been refined to keep all of the measurements and equipment as straightforward as possible and provide scientific methodologies suitable to the skill levels of the students. Therefore, in the current Teacher's Guide, while some of the protocols initiated in previous versions of the Teacher's Guide remain unchanged, some have been improved, and some new protocols have been added to the GLOBE science program. This evolution is an outgrowth of the desire of GLOBE Program management, scientists, and educators to be responsive to the needs of the primary and secondary education community as well as to provide for the best environmental science.

All of the GLOBE schools are strongly encouraged to participate in the full range of GLOBE science measurements. Additionally, schools are strongly encouraged to take advantage of the learning activities which are designed to promote the learning of science in conjunction with the protocols.

GLOBE Science and Inquiry Processes

The Teacher's Guide facilitates the learning of science by use of the inquiry process. The inquiry process used by the GLOBE Program is an approach to learning which parallels the scientific method used by scientists. This process is represented in the combined package of the protocols and learning activities. The protocols focus on data collection and data reporting. The activities broaden from the data collection and data reporting to include other parts of the inquiry process such as formulation of hypotheses, analysis of data, and drawing of conclusions.

The science process used by researchers parallels the inquiry process used at the K-12 level. The primary difference is the outcome for each group. In schools, the primary outcome is learning science. At the research level, the outcome is generation of knowledge. The data collection and data reporting done by the students provide data to the research community and these data are used in the generation of new knowledge. The scientific research community analyzes the data, draws conclusions and reports results which are communicated back to the teachers and students.

In GLOBE, the science and inquiry processes are linked via communication between the GLOBE students and scientists. This communication occurs when the students' data are reported for use in the generation of knowledge by the science community and by the transmission of visualizations and results of research by the science community to the schools. GLOBE scientists answering the questions of teachers and students in person, through correspondence, and over the World Wide Web in real time are included in this communication.

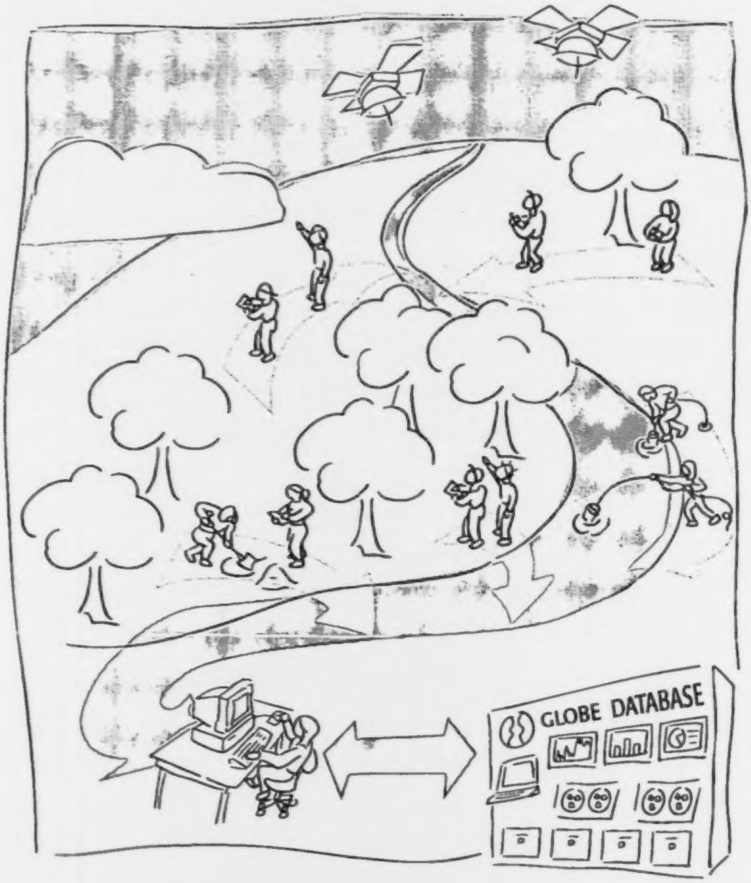
Science Concepts and Skills as Key Elements of the GLOBE Teacher's Guide

To improve students' understanding of science, the scientist/educator teams have developed learning activities to help students learn and apply science content and thinking skills. The scientists defined the key science concepts in simple terms. GLOBE scientists and educators then designed educational activities to help students learn the key science concepts along with the science protocols. Students and teachers use the learning activities to strengthen their understanding, explore local and global data, experience the scientific method, and design and implement their own investigations. In the process, students also focus on issues of data quality. Since quality science is dependent on quality data, calibration and quality control procedures are specified in the protocols and are critical to the success of GLOBE. Specific learning activities reinforce the importance of data quality.

A major challenge in preparing the Teacher's Guide was making it appropriate for a broad spectrum of grade levels. Key science concepts and skills are represented in each protocol and learning activity. The concepts and skills are used in two ways. First, the concepts and skills guide the development process. Second, the concepts and skills help the teachers integrate the learning activities into their local curriculum.

The GLOBE Program is always evolving and will continue to provide science and learning activities that take advantage of the increased experience and enhanced skills that students have acquired to introduce more complex science concepts, more sophisticated insights into environmental research, and improved science achievement. As students achieve higher levels of scientific understanding, they will be challenged to move from a specific discipline to a multi-disciplinary perspective and from a local to a global perspective.

Implementation Guide for Teachers


GLOBE DATABASE

GLOBE™ Science and Education Program

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What Will You and Your Students Do in the GLOBE Program?

Your students will be carrying out a series of investigations that scientists have designed to gather data about the Earth and how it functions as a global system. Students will be using instruments and their own senses to observe the environment at multiple sites near your school. They will record the data they gather, save it in a permanent school data record, and send it to the GLOBE Student Data Server (our database) using the Internet and the World Wide Web or email where the Web is not readily available.

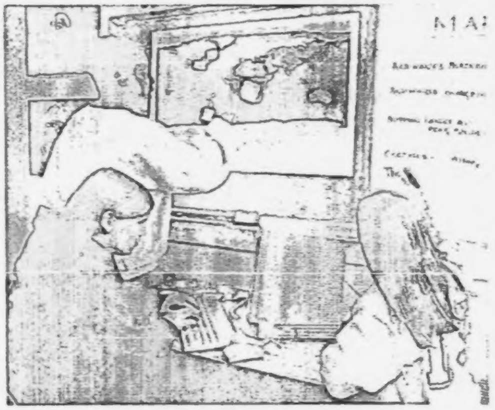
In addition to carrying out these measurements in collaboration with GLOBE scientists, you have the option of doing some of the learning activities with your students, either as described here, or in whatever form is most appropriate for your local curriculum needs.

Do not worry if you're not an experienced science teacher. The learning materials provide a range of activities, from beginning activities to be used by teachers of young children who might have had little experience with science, to advanced activities for the advanced level. Each learning activity provides the background information needed to do the activity.

Each of the protocols and learning activities includes a designation of recommended grade levels, in three categories:

Beginning - Ages 5-9 years
Intermediate - Ages 10-13 years
Advanced - Ages 14-18

However, do not feel locked in by these age level distinctions. Many of the activities can be adapted to lower or higher levels, based on your students' needs and abilities.



Ultimately, your GLOBE classroom and the study sites where you make the measurements are likely to be very busy places for science and learning. Your students will observe and make measurements, record their data, come to understand accuracy and precision, share their data with other students and scientists, conduct labs, formulate questions, test hypotheses, and develop theories to make sense of the data. They will use a variety of scientific instruments, calibrate those instruments, and try to understand potential sources of error in the measurements they take with the instruments. They will work with real data, some that they collect and some that they obtain from other GLOBE schools around the world.

There are six key educational elements of the GLOBE program.

1. **Selecting local study and sample sites -** Based on guidelines provided here, you will pick local study sites for your recurring measurements along with sample sites which the students will normally visit only once. For example, the Hydrology Study Site should be a nearby river, lake, bay, ocean, or pond. All of the study and sample sites will be within your 15 km x 15 km GLOBE Study Site, with your school at its center.
2. **Doing measurements carefully on a regular schedule -** Students should begin with one measurement and then, over the course of a few months, add new measurements one-by-one as they learn how to do them. As their teacher, you need to make sure your students understand the measurements and do them accurately. Most of the measurement protocols specify a regular schedule for taking data and some require observations at specific times. Weather measurements, which are daily, can be done most easily at a sight adjacent to your school. Others, such as the weekly hydrology measurements, will require going to the selected study site. Working with your students, their parents, and your school community to have measurements made during weekends and school vacations is also important in obtaining an accurate record of your local environment for use by scientists and your students.
3. **Submitting the data -** All data should be submitted to the GLOBE Student Data Server. The most common way to submit data is by computer and the Internet.
4. **Doing the learning activities -** Each investigation has a set of learning activities that help your students learn more about the science domains, the instruments and procedures for the measurements, and the ways that students and scientists can use the data collected. We hope you will use these learning activities, either as described, or by adapting them to your local needs. Your experiences in using these learning activities or new learning activities you develop can be shared with other GLOBE teachers to benefit the entire program.
5. **Using GLOBE systems on the Internet to explore and communicate -** GLOBE has created some powerful (and easy to use) computer software, which enables you to communicate with other schools and with the GLOBE scientists. It also lets your students see and interact with local and worldwide maps on which the GLOBE data are displayed.
6. **Promoting student investigations -** Ultimately, our hope is that your students will do their own investigations at local sites, or by using the GLOBE software and data collected by other students worldwide. Your students might even make some new scientific discoveries of their own!

Science Values and GLOBE Measurements

There are four characteristics needed in GLOBE measurements that will form a foundation for their ultimate contributions to science. They are accuracy, consistency, persistence, and coverage. If all of us contributing to GLOBE can cooperate to produce data sets which have all four characteristics, our contribution to world-wide understanding of our environment will be enhanced.

Accuracy is the foundation of all scientific observation. For us, care in taking the measurements is the first step. Also, the equipment we use and our effort to keep it in good condition are important. Lastly, we all need to strive for perfection in recording data entries and reporting them to the data archive.

Consistency means that the data from any GLOBE school can be used together with the data from all the others to produce a consistent picture of what is happening beyond our own individual sites. The visualizations illustrate this characteristic. Consistency is also important over time. Students at each school are building a climate record of their location. To see changes and trends in our individual environments, the data that have been taken in the past must be directly comparable to the data we are taking today. Faithful adherence to the protocols and careful documentation of changes in our methods and techniques is the best approach to achieving this characteristic.

Persistence is required to keep interruptions in our climate records to a minimum. Occasional measurements are useful, but regular observations provide more information, allowing a greater understanding of what is happening at a measurement site. Also, regular observations are often easier to interpret and are used with greater confidence, especially when unusual phenomena are measured. The longer a consistent climate record is, the more valuable it is. Think of the lucky GLOBE students five years from now who will be able to look at variations and trends in the environment of their school!

Coverage of whole regions, countries, continents, and as much of our planet as possible also will enhance the value of our data sets. The differences in the visualizations where there are many schools versus only a few illustrate this. The properties of our environment vary over many different spatial scales — locally within our 15 km by 15 km GLOBE Study Sites, regionally across our metropolitan areas, states, or countries, and globally. Measuring these properties on these different scales is essential, and as the GLOBE program grows to include more schools in more countries, the importance of our collective contributions will continue to grow.

Individually and collectively, all of us in GLOBE must strive for accurate and consistent measurements made persistently across our global environment.

GLOBE Measurements in Time and Space

We live on a changing planet. Moment by moment, day to day, year after year change is all around us. Some changes are cycles such as the day, the variations in the tides as the moon orbits the Earth, and the yearly change of seasons. Other changes seem to come and go such as clouds and rain storms. Still other, gradual change we see as growth such as with trees or other plants or even ourselves. Sometimes big changes happen quickly as when a volcano erupts or a fire sweeps over the land. Each type of change happens on its own time scale.

All of us, especially scientists, want to understand the changes happening all around us. Why do changes happen; how do different changes influence each other; what will happen next? To understand change, and in some cases predict it, we must measure our environment, but we can't measure everything happening in our environment, everywhere, all the time. Instead we try to make measurements in a way which will give us enough data to tell what is happening.

In GLOBE, the atmospheric measurements are designed to be made once each day while streams, rivers, lakes, bays, the ocean, or ponds are measured weekly, and soil characteristics in a given place need only be measured once. Other measurements are taken at different intervals. Some measurements are snap shots - what types of clouds do we see right now? Some measurements tell us what has happened over a period of time - how much rain fell in the last day? The time scale on which we make the measurements allows us to analyze the different changes in our environment.

Our environment also varies from place to place. We live on mountains, valleys, plains, coasts. We live in cities, suburbs, villages, and the country side. In some places grasslands, fields or forests surround us for as far as we can see. In other places, a mountain may rise next to our town or there may be forests, fields, and lakes all mixed together. On a finer scale, in one place there is a tree or a grass, in another a road, in another a house, and in another a stream. Sometimes we can see that it is raining near-by but not where we are. Clearly, our environment varies on different distance scales.

Again, we cannot measure everything about our environment everywhere. So we space our observations so as to measure the variations on their different spatial scales. In GLOBE, each school is at the center of a GLOBE Study Site which is a square 15 km on a side. These sites can overlap or be shared among schools. In GLOBE, students learn how to determine the land cover of this whole site looking at variations down to a spatial scale of 30 meters. Within this overall site, students at a GLOBE school make recurring measurements at specific locations known as *study sites*. Other measurements are made only once at a number of *sample sites*. As the number of GLOBE schools increases, more of our global environment is covered by good measurements and variations over smaller distances can be studied.

With all the changes in our environment over time and variations over space, our ability to understand our environment is limited by the number of measurements we can make. Each GLOBE school has the opportunity to add significantly to the total set of measurements being made around the world. As we keep making GLOBE measurements carefully and consistently, we are giving ourselves and everyone else a gift of better knowledge of our environment both locally and globally.

What Are the Domains of GLOBE Science Research?

In the broadest sense, the entire planet Earth is the domain of GLOBE science research. By collecting environmental data from around the world, scientists (and students) will have a better understanding of Earth and its interrelated cycles which comprise an integrated system. While scientists already have access to much data about Earth, GLOBE students will provide important new data to help the scientists. One value of the GLOBE student data is that it is worldwide, providing measurements from thousands of locations. Another value is that students do several different types of measurements at the same time, enabling scientists to study how Earth's land, air, water and biology systems interact. Finally, GLOBE students contribute their own analyses of their local study sites, becoming in a very real sense, the world's experts on their own study area, which will in turn help the scientists in their research.

Currently, there are four domains of GLOBE scientific research. Each is detailed in one of the GLOBE investigations:

Atmosphere – Your students will conduct daily measurements of cloud cover and type, air temperature, precipitation, and its pH.

Hydrology – Your students will do weekly measurements of water transparency, temperature, dissolved oxygen, pH, either conductivity or salinity, alkalinity, and nitrate-nitrogen of a body of water near the school.

Soil – Your students will expose a soil profile, take soil samples, and analyze them to determine the characteristics of various soil layers. They also will do daily to monthly measurements of soil moisture at various depths and locations, measure the rate at which water infiltrates the soil, and take weekly measurements of near-surface soil temperature.

Land Cover/Biology – Your students will monitor change in a local land Biology Study Site and observe other Quantitative Land Cover Sample Sites where they will identify the dominant and subdominant species of vegetation and take measurements that help scientists assess the total amount of biomass on the site. Your students will also compare what they measure on the ground at Qualitative as well as Quantitative Land Cover Sample Sites with images of the same area taken from space by the Thematic Mapper instrument aboard the Landsat satellite.

In addition to these direct investigations, there are two supportive investigations included in GLOBE:

GPS – The Global Positioning System (GPS) is a new technology that enables you and your students to determine the latitude, longitude, and elevation, of your various sites using a small hand-held receiver and a set of Earth-orbiting satellites. This information is essential so that scientists and others will always know where your measurements were taken.

Seasons Investigation – In this investigation, learning activities are provided that you can use to help your students analyze the data they have collected to investigate annual seasonal changes in their local study sites and elsewhere in the world. In so doing, your students develop skills of scientific investigation and learn how the atmosphere, hydrology, soil and land cover measurements are interrelated.

Introduction

Implementing GLOBE in Your School

Obtaining Instruments

Each of the investigations requires use of accurate, reliable, and calibrated instruments that meet the specifications developed by the GLOBE scientists to ensure consistent and accurate measurements for use by the international environmental science community. The instrument specifications are contained in the *Toolkit*.

You have four choices:

1. Purchase all or some of the instruments.
   - Purchase individual instruments from several suppliers.
   - Purchase the instruments from one supplier as a kit.
2. Use your own instruments.
   If you already have instruments that meet GLOBE specifications in your school, you may use them. You must be sure, however, that they meet the accuracy and calibration requirements.
3. Make some of your instruments.
   Following directions given in this *Teacher's Guide* and at the teacher training workshops, you will be able to construct some of the instruments.
4. Borrow instruments or share some of the instruments with other schools.
   You may be able to borrow instruments that are needed infrequently from another local school or share one instrument among two or more GLOBE schools. In the case of the GPS receiver, it is available on loan from GLOBE or through your GLOBE Country Coordinator.

Training and Implementation

Every teacher who takes responsibility for the GLOBE measurements must have attended one GLOBE sanctioned workshop. Teachers who have received GLOBE training must undertake the responsibility of making sure that the others in their school receive correct training. If you have attended a GLOBE workshop and are comfortable implementing new GLOBE measurement protocols, then you are encouraged to do so even though your training may not have covered them. If you are uncomfortable with the new protocols, you can obtain assistance from the GLOBE Help Desk or attend another GLOBE training workshop.

Establish Learning Communities

School Learning Community

An effective, interesting, and exciting way to implement GLOBE in your school is to involve many teachers. If you can share the work with colleagues, it will make it easier and more fun. More importantly, it is helpful for you to have colleagues with whom you can share ideas, brainstorm, and plan. Research and experience have shown over and over again that innovative programs such as GLOBE have a better chance of success if they are undertaken by a team of mutually-supportive teachers than if tackled alone.

One strategy for building a learning community in your school is the development of a school implementation plan which details a division of labor among teachers at the school for the implementation of the various GLOBE topic areas – atmosphere, hydrology, soil, and land cover/biology. The plan could identify the most appropriate locations in the school curricula for integrating each of the GLOBE areas. The plan also could have a section on training and involving additional colleagues. Schools with a single GLOBE trained teacher might choose to get additional colleagues involved in the implementation of GLOBE at their school. This can be done by having the initially trained GLOBE teacher train others at the school or the other teachers can attend any one of a number of GLOBE workshops. The plan might also describe how equipment and computer facilities will be obtained and factored into the instructional plan.

A timetable for all major activities is desirable. One strategy might be to develop a GLOBE implementation plan as part of a classroom activity involving students. They could come up with ideas for addressing issues such as the placement of the weather station, identification of classes or subjects for inclusion, etc.

In order to provide an identity for your school learning community and for GLOBE activities in your school, you may want to establish a GLOBE headquarters in some prominent location, perhaps in the library or resource center. Here you can display GLOBE posters, have a collection of books about planet Earth, display student work, and perhaps have a computer set up with an Internet connection ready to log onto GLOBE.

In addition, you may want to place posters and other materials in a prominent place near the school office or entrance, identifying your school as a participant in the GLOBE Program. Students may create ongoing displays of the data they are collecting. Photos of students at the study and sample sites making measurements and maps locating these sites will inform viewers of the scope of your work.

The school-based plan can be extended to the school district, thereby developing a strategy for the implementation of GLOBE at various schools linking activities from beginning to intermediate and advanced levels.

Neighborhood Learning Community

Another area where you might build a learning community is in your neighborhood. There are many people and organizations which may be interested in your GLOBE activities. Some of those people or organizations might be recruited to assist you with a variety of activities. For example, service clubs such as Rotary, business and industry or other organizations, may be willing to provide support for equipment purchases, research activities or presentations.

Community volunteers, including parents, may be able to help with a variety of GLOBE related tasks or activities. It is important to cultivate an ongoing relationship with key members of the community. Let them know about your successes and plans. Publicize events and invite them to attend. If people provide money or services, then be sure to thank them by letter and acknowledgment in public forums. Areas where volunteers may be able to assist include:

- provide transportation for students to and from the study and sample sites
- help collect data on weekends or during school vacations
- help students use the GLOBE World Wide Web resources from home computers
- accompany the class on field trips to the sites
- help younger students make the daily measurements at the weather station
- help edit and publish a GLOBE newsletter to be sent home providing updates on what the students are doing in their GLOBE work
- help set up a GLOBE exhibit in a public area of the school or the community
- help prepare press releases about GLOBE for local newspapers.

Geographically Distributed Research Learning Community

It is also possible to establish geographically distributed research teams which can become a wider learning community. Schools in various parts of a country or the world can collaborate on research activities. These activities can compare various data sets or explore any number of phenomena. Some may choose to collaborate on learning activities. In order to establish a geographically distributed learning community, it is important to first establish the task or function you wish to collaborate on then decide on the geographic scope. Communication vehicles can include GLOBEMail or other methods such as regular post. Your research community can be expanded by inviting GLOBE scientists or other researchers to participate as mentors and provide support for your school to school investigation. Once you have completed your investigation it is important to think about how you might communicate the results to others. You might consider doing presentations at your school, school board meeting, community forum or submit your work in the form of a paper to a journal.

How Is This Guide Organized?

There are six investigations in this teacher's guide:

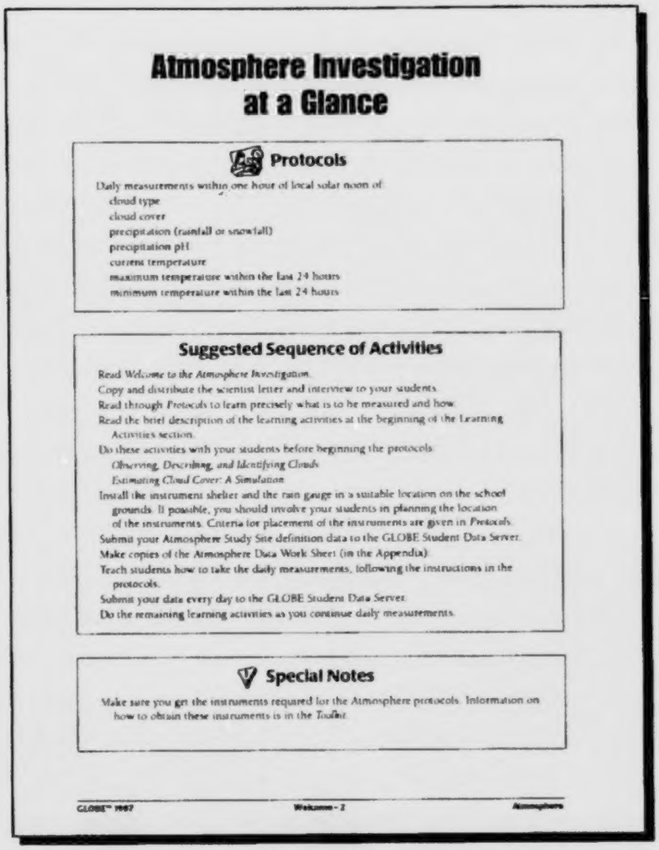
Atmosphere Investigation
Hydrology Investigation
Soil Investigation
Land Cover/Biology Investigation
GPS Investigation
Seasons Investigation

All of the investigations have the same structure, as detailed below. Each provides background information about the subject, instructions on how to do the measurements, and descriptions of a set of learning activities.

As detailed on the next few pages, each investigation has the following sections:

Welcome to the Investigation
Introduction
Protocols
Learning Activities
Appendix

Note that the *Seasons Investigation* does not include any additional measurements, and so, it does not have a Protocol section.



Atmosphere Investigation at a Glance

Protocols

Daily measurements within one hour of local solar noon of
- cloud type
- cloud cover
- precipitation (rainfall or snowfall)
- precipitation pH
- current temperature
- maximum temperature within the last 24 hours
- minimum temperature within the last 24 hours

Suggested Sequence of Activities

Read *Welcome to the Atmosphere Investigation*.
Copy and distribute the scientist letter and interview to your students.
Read through *Protocols* to learn precisely what is to be measured and how.
Read the brief description of the learning activities at the beginning of the Learning Activities section.
Do these activities with your students before beginning the protocols:
  Observing, Describing, and Identifying Clouds
  Estimating Cloud Cover: A Simulation
Install the instrument shelter and the rain gauge in a suitable location on the school grounds. If possible, you should involve your students in planning the location of the instruments. Criteria for placement of the instruments are given in *Protocols*.
Submit your Atmosphere Study Site definition data to the GLOBE Student Data Server.
Make copies of the Atmosphere Data Work Sheet (in the Appendix).
Teach students how to take the daily measurements, following the instructions in the protocols.
Submit your data every day to the GLOBE Student Data Server.
Do the remaining learning activities as you continue daily measurements.

Special Notes

Make sure you get the instruments required for the Atmosphere protocols. Information on how to obtain these instruments is in the *Toolkit*.

GLOBE™ 1997 Welcome - 2 Atmosphere

Investigation at a Glance

Each investigation begins with Investigation at a Glance. This is a quick overview of the investigation. It summarizes the measurements your students will do. It also recommends a sequence in which you could interweave the learning activities and the protocols. There are many differences among schools and their approaches to GLOBE, and there are many differences among the needs and abilities of individual students. Some schools will just implement the protocols. Others may find that students need more background in the science domain in order to do the protocol.

The general sequence within each investigation is:

1. Students learn about the scientists and their domain of science
2. Students learn how to do the protocol, do pre-protocol learning activities, practice measurement techniques;
3. Students begin making measurements;
4. Students learn more about the domain by studying their local data and data from other schools around the world and doing post-protocol learning activities.

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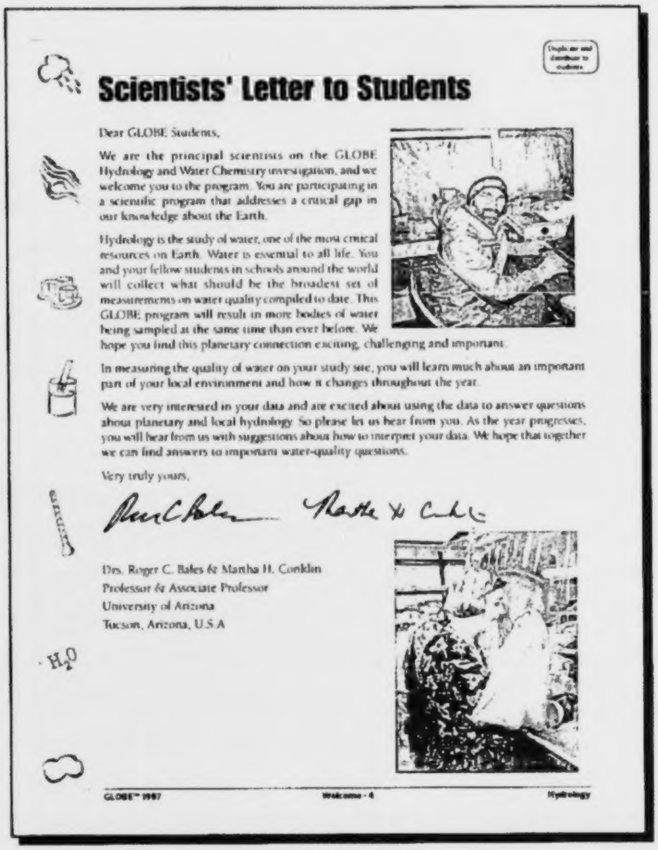

Scientists' Letter to Students

Dear GLOBE Students,

We are the principal scientists on the GLOBE Hydrology and Water Chemistry investigation, and we welcome you to the program. You are participating in a scientific program that addresses a critical gap in our knowledge about the Earth.

Hydrology is the study of water, one of the most critical resources on Earth. Water is essential to all life. You and your fellow students in schools around the world will collect what should be the broadest set of measurements on water quality compiled to date. This GLOBE program will result in more bodies of water being sampled at the same time than ever before. We hope you find this planetary connection exciting, challenging and important.

In measuring the quality of water on your study site, you will learn much about an important part of your local environment and how it changes throughout the year.

We are very interested in your data and are excited about using the data to answer questions about planetary and local hydrology. So please let us hear from you. As the year progresses, you will hear from us with suggestions about how to interpret your data. We hope that together we can find answers to important water-quality questions.

Very truly yours,

Drs. Roger C. Bales & Martha H. Conklin
Professor & Associate Professor
University of Arizona
Tucson, Arizona, U.S.A

GLOBE™ 1997 Welcome - 4 Hydrology

Welcome to the Investigation

The Welcome section helps you and your students get to know the scientists who are responsible for this investigation. It includes a letter from and an interview with the scientists who serve as principal investigators for the investigation. You should copy and distribute or in some way make the scientists' letter and the scientists' interview available to your students.

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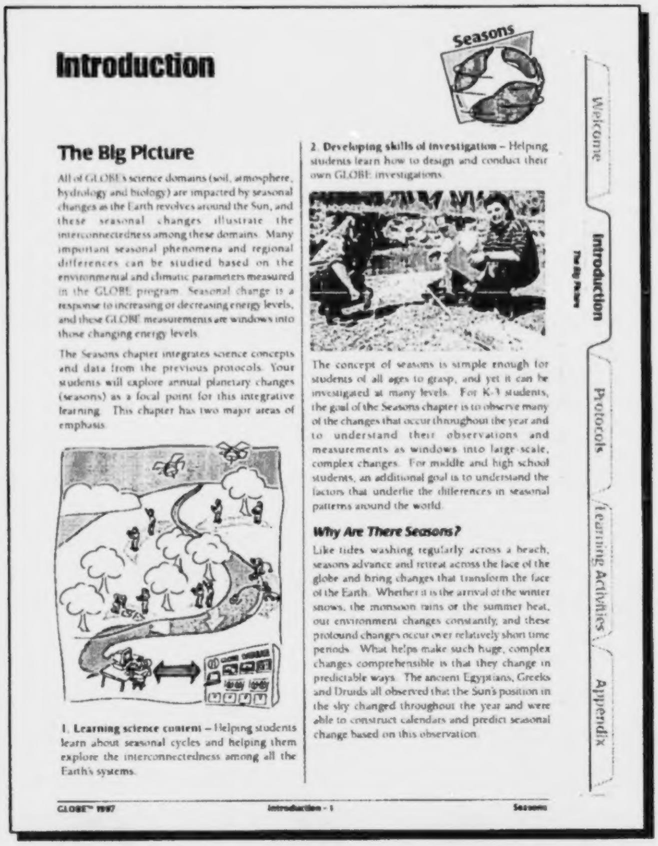

Introduction

The Big Picture

All of GLOBE's science domains (soil, atmosphere, hydrology and biology) are impacted by seasonal changes as the Earth revolves around the Sun, and these seasonal changes illustrate the interconnectedness among these domains. Many important seasonal phenomena and regional differences can be studied based on the environmental and climatic parameters measured in the GLOBE program. Seasonal change is a response to increasing or decreasing energy levels, and these GLOBE measurements are windows into those changing energy levels.

The Seasons chapter integrates science concepts and data from the previous protocols. Your students will explore annual planetary changes (seasons) as a focal point for this integrative learning. This chapter has two major areas of emphasis.

1. **Learning science content** – Helping students learn about seasonal cycles and helping them explore the interconnectedness among all the Earth's systems.

2. **Developing skills of investigation** – Helping students learn how to design and conduct their own GLOBE investigations.

The concept of seasons is simple enough for students of all ages to grasp, and yet it can be investigated at many levels. For K-3 students, the goal of the Seasons chapter is to observe many of the changes that occur throughout the year and to understand their observations and measurements as windows into large-scale, complex changes. For middle and high school students, an additional goal is to understand the factors that underlie the differences in seasonal patterns around the world.

Why Are There Seasons?

Like tides washing regularly across a beach, seasons advance and retreat across the face of the globe and bring changes that transform the face of the Earth. Whether it is the arrival of the winter snows, the monsoon rains or the summer heat, our environment changes constantly, and these profound changes occur over relatively short time periods. What helps make such huge, complex changes comprehensible is that they change in predictable ways. The ancient Egyptians, Greeks and Druids all observed that the Sun's position in the sky changed throughout the year and were able to construct calendars and predict seasonal change based on this observation.

GLOBE™ 1997 Introduction - 1 Seasons

Introduction

The Introduction section sets the stage for the investigation. It provides important background information and helps you and your students appreciate the science of the investigation. It includes:

- an introduction to the *big picture* that puts this investigation in perspective;
- advice on how to prepare for the field work;
- a description of the student learning goals; and
- ideas on how you can assess student learning.

These sections give you, the teacher, background information on the investigation to help you guide the students in their work on GLOBE.

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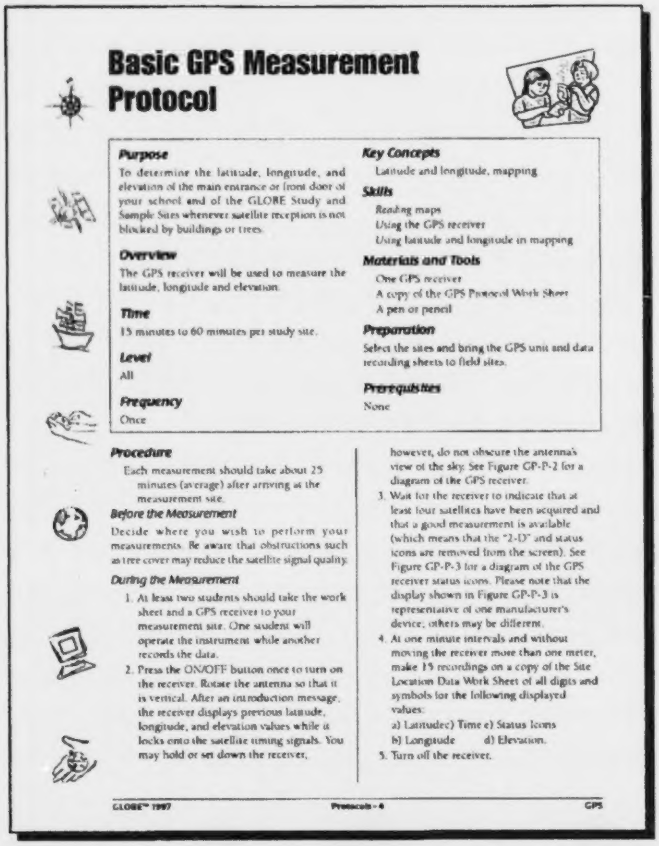

Basic GPS Measurement Protocol

Purpose
To determine the latitude, longitude, and elevation of the main entrance or front door of your school and of the GLOBE Study and Sample Sites whenever satellite reception is not blocked by buildings or trees.

Overview
The GPS receiver will be used to measure the latitude, longitude and elevation.

Time
15 minutes to 60 minutes per study site.

Level
All

Frequency
Once

Key Concepts
Latitude and longitude, mapping

Skills
Reading maps
Using the GPS receiver
Using latitude and longitude in mapping

Materials and Tools
One GPS receiver
A copy of the GPS Protocol Work Sheet
A pen or pencil

Preparation
Select the sites and bring the GPS unit and data recording sheets to field sites.

Prerequisites
None

Procedure

Each measurement should take about 25 minutes (average) after arriving at the measurement site.

Before the Measurement

Decide where you wish to perform your measurements. Be aware that obstructions such as tree cover may reduce the satellite signal quality.

During the Measurement

1. At least two students should take the work sheet and a GPS receiver to your measurement site. One student will operate the instrument while another records the data.
2. Press the ON/OFF button once to turn on the receiver. Rotate the antenna so that it is vertical. After an introduction message, the receiver displays previous latitude, longitude, and elevation values while it locks onto the satellite timing signals. You may hold or set down the receiver, however, do not obscure the antenna's view of the sky. See Figure GP-P-2 for a diagram of the GPS receiver.
3. Wait for the receiver to indicate that at least four satellites have been acquired and that a good measurement is available (which means that the "2-D" and status icons are removed from the screen). See Figure GP-P-3 for a diagram of the GPS receiver status icons. Please note that the display shown in Figure GP-P-3 is representative of one manufacturer's device; others may be different.
4. At one minute intervals and without moving the receiver more than one meter, make 15 recordings on a copy of the Site Location Data Work Sheet of all digits and symbols for the following displayed values:
   a) Latitudec) Time e) Status Icons
   b) Longitude d) Elevation.
5. Turn off the receiver.

GLOBE™ 1997 Protocols - 4 GPS

Protocols

This section describes, in detail, how to conduct the measurements required for the investigation. This includes:

- how to select the study site for the investigation;
- the instruments you need for the investigation;
- how to conduct the measurements; and
- how to submit the data to the GLOBE Student Data Server.

The precise instructions on how to conduct the measurements are called protocols. You will need to read these protocols very carefully before you take the measurements. Later in this chapter, we offer some advice on *How to Teach a Protocol*. Detailed specifications of the instruments you will need to do the protocols are provided in the *Toolkit*.

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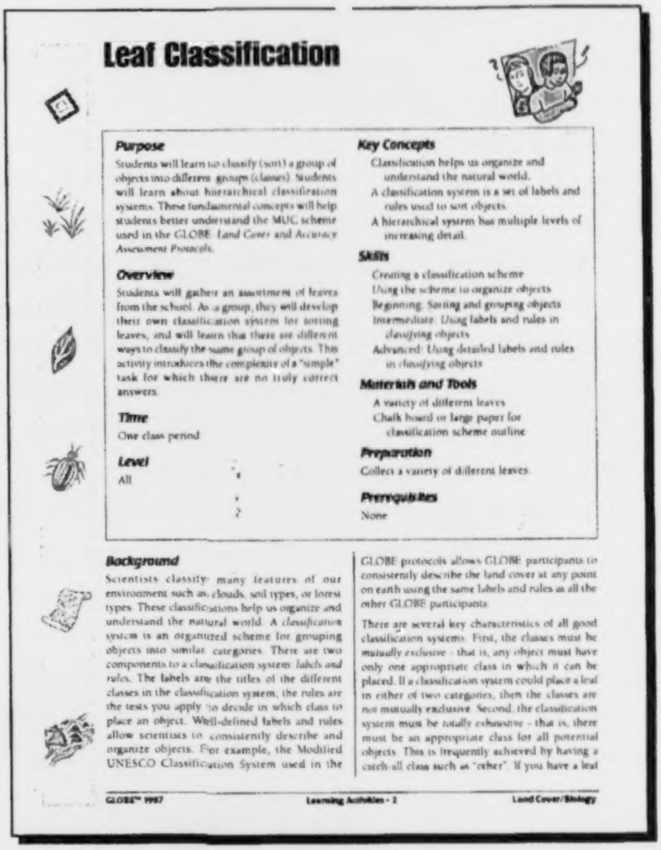

Leaf Classification

Purpose

Students will learn to classify (sort) a group of objects into different groups (classes). Students will learn about hierarchical classification systems. These fundamental concepts will help students better understand the MUC scheme used in the GLOBE *Land Cover and Accuracy Assessment Protocols*.

Overview

Students will gather an assortment of leaves from the school. As a group, they will develop their own classification system for sorting leaves, and will learn that there are different ways to classify the same group of objects. This activity introduces the complexity of a "simple" task for which there are no truly correct answers.

Time

One class period

Level

All

Key Concepts

Classification helps us organize and understand the natural world.
A classification system is a set of labels and rules used to sort objects.
A hierarchical system has multiple levels of increasing detail.

Skills

Creating a classification scheme
Using the scheme to organize objects
Beginning: Sorting and grouping objects
Intermediate: Using labels and rules in *classifying* objects
Advanced: Using detailed labels and rules in *classifying* objects

Materials and Tools

A variety of different leaves
Chalk board or large paper for classification scheme outline

Preparation

Collect a variety of different leaves

Prerequisites

None

Background

Scientists classify many features of our environment such as clouds, soil types, or forest types. These classifications help us organize and understand the natural world. A *classification system* is an organized scheme for grouping objects into similar categories. There are two components to a classification system: *labels and rules*. The labels are the titles of the different classes in the classification system; the rules are the tests you apply to decide in which class to place an object. Well-defined labels and rules allow scientists to consistently describe and organize objects. For example, the Modified UNESCO Classification System used in the GLOBE protocols allows GLOBE participants to consistently describe the land cover at any point on earth using the same labels and rules as all the other GLOBE participants.

There are several key characteristics of all good classification systems. First, the classes must be *mutually exclusive* - that is, any object must have only one appropriate class in which it can be placed. If a classification system could place a leaf in either of two categories, then the classes are not mutually exclusive. Second, the classification system must be *totally exhaustive* - that is, there must be an appropriate class for all potential objects. This is frequently achieved by having a catch-all class such as "other". If you have a leaf

GLOBE™ 1997 Learning Activities - 2 Land Cover/Biology

Learning Activities

In the Learning Activities section of each investigation a set of activities is provided that you can use to help students learn more about the instruments and protocols, understand the data they collect, and use the GLOBE data to further understand the investigation's key ideas.

At the beginning of each Learning Activity is a box with essential information, in a standard form to help you quickly determine whether this activity is appropriate for your students, based on their ages, interests, and ability levels. In the box at the beginning of the learning activities, Time usually refers to the number of 50 - minute class periods recommended for this activity. Level refers to recommended age levels in three categories: beginning (ages 5-9 years), intermediate (ages 10-13 years), and advanced (ages 14-18 years).

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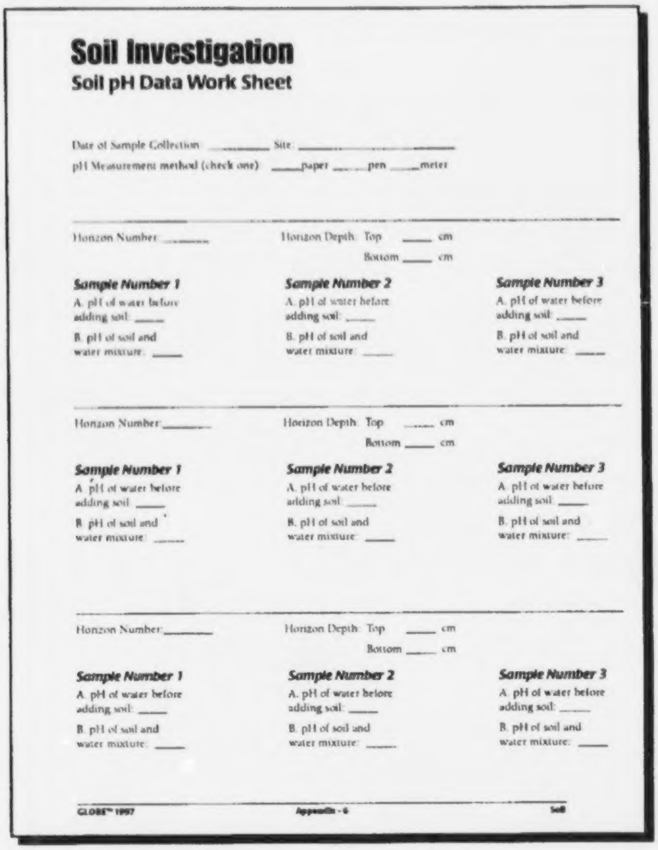

Soil Investigation
Soil pH Data Work Sheet

Date of Sample Collection: ________ Site: ________________
pH Measurement method (check one): ____paper ____pen ____meter

Horizon Number: ______ Horizon Depth: Top ____ cm
Bottom ____ cm

Sample Number 1	***Sample Number 2***	***Sample Number 3***
A. pH of water before adding soil: ____	A. pH of water before adding soil: ____	A. pH of water before adding soil: ____
B. pH of soil and water mixture: ____	B. pH of soil and water mixture: ____	B. pH of soil and water mixture: ____

Horizon Number: ______ Horizon Depth: Top ____ cm
Bottom ____ cm

Sample Number 1	***Sample Number 2***	***Sample Number 3***
A. pH of water before adding soil: ____	A. pH of water before adding soil: ____	A. pH of water before adding soil: ____
B. pH of soil and water mixture: ____	B. pH of soil and water mixture: ____	B. pH of soil and water mixture: ____

Horizon Number: ______ Horizon Depth: Top ____ cm
Bottom ____ cm

Sample Number 1	***Sample Number 2***	***Sample Number 3***
A. pH of water before adding soil: ____	A. pH of water before adding soil: ____	A. pH of water before adding soil: ____
B. pH of soil and water mixture: ____	B. pH of soil and water mixture: ____	B. pH of soil and water mixture: ____

GLOBE™ 1997 Appendix - 6 Soil

Appendix

The Appendix to each investigation includes Data Work Sheets that can be copied and used by students when they collect their data. Using these sheets reinforces the protocols and helps students remember to record all needed observations. Some of the Appendices contain extensive tables or write-ups that students should take with them when doing the protocols. Also, copies of the Data Entry Sheets from the GLOBE Student Data Server are provided. These sheets are the World Wide Web pages students use to enter their GLOBE data. If your school does not have access to the Web and you are using email or some other means to report your data, these pages will help you and your students better understand the data entries expected by GLOBE. A glossary is provided of the special terms used in connection with the investigation. Also, other material supportive of the investigation is included in the Appendix. Additional items relating to one or more investigations are found in the *Toolkit*.

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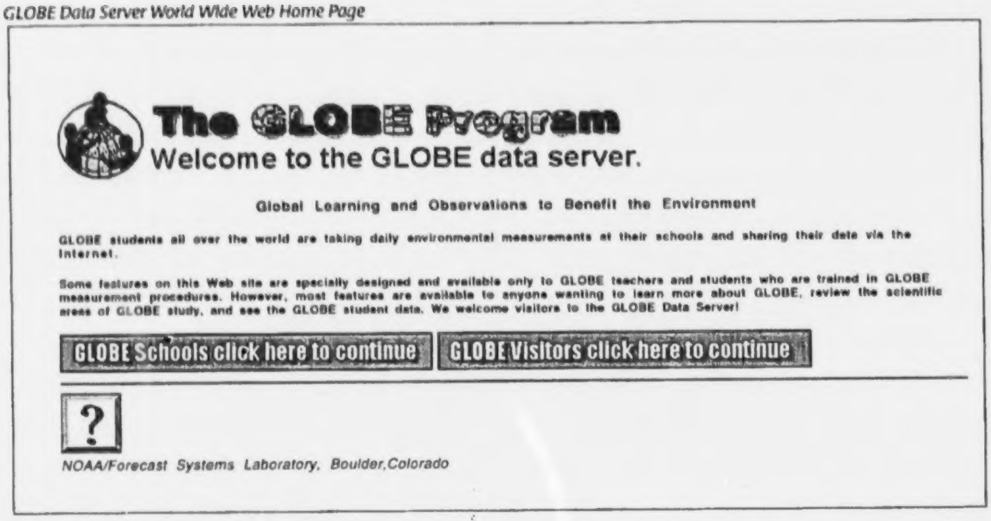
GLOBE Data Server World Wide Web Home Page



The GLOBE Program

Welcome to the GLOBE data server.

Global Learning and Observations to Benefit the Environment

GLOBE students all over the world are taking daily environmental measurements at their schools and sharing their data via the Internet.

Some features on this Web site are specially designed and available only to GLOBE teachers and students who are trained in GLOBE measurement procedures. However, most features are available to anyone wanting to learn more about GLOBE, review the scientific areas of GLOBE study, and see the GLOBE student data. We welcome visitors to the GLOBE Data Server!

GLOBE Schools click here to continue
GLOBE Visitors click here to continue
?

NOAA/Forecast Systems Laboratory, Boulder,Colorado

GLOBE Telecommunications

GLOBE uses computer telecommunications for students to submit their data, and to help students explore the data for their own investigations. GLOBE telecommunications use the Internet and the World Wide Web.

In brief, here is how it works:

Step 1: Connect your computer to the Internet - The Internet is a network connecting computers all over the world. From your school, you can connect your computer to the Internet through the phone lines or through some special wiring that might already be in place. You may want to have a local computer specialist help you with this step.

Step 2: Install a *browser* that lets you use the World Wide Web - With the World Wide Web, you can use the Internet to get information from thousands of businesses, universities, government agencies, and individuals. Each of these organizations has created one or more easy and friendly starting point called *home pages* that let you get information about the organization and its products or services (most home pages are quite visual and engaging). To use the World Wide Web and access these home pages, you need to install special software called a browser on your computer. There are many different brands of browsers, some of which are free, and all of which accomplish the same task - letting you access the World Wide Web. You might want to have a local computer specialist help you select and install the browser and get you started on the Web.

Step 3: Now you are ready to explore GLOBE on the World Wide Web - GLOBE has a Web home page (http://www.globe.gov) that is designed for the general public. This GLOBE home page is a starting point that easily leads to the forms to submit data, information about the scientists' research, and some very interesting visualizations to help your students learn and explore.

As a GLOBE school, you will generally start at another GLOBE home page. It will be a very important part of your participation in GLOBE.

Below are some samples from GLOBE's Web pages. One is a Data Entry Sheet with which you submit data. The others are a sample visualizations or showing maps based on student temperature data or reference data.

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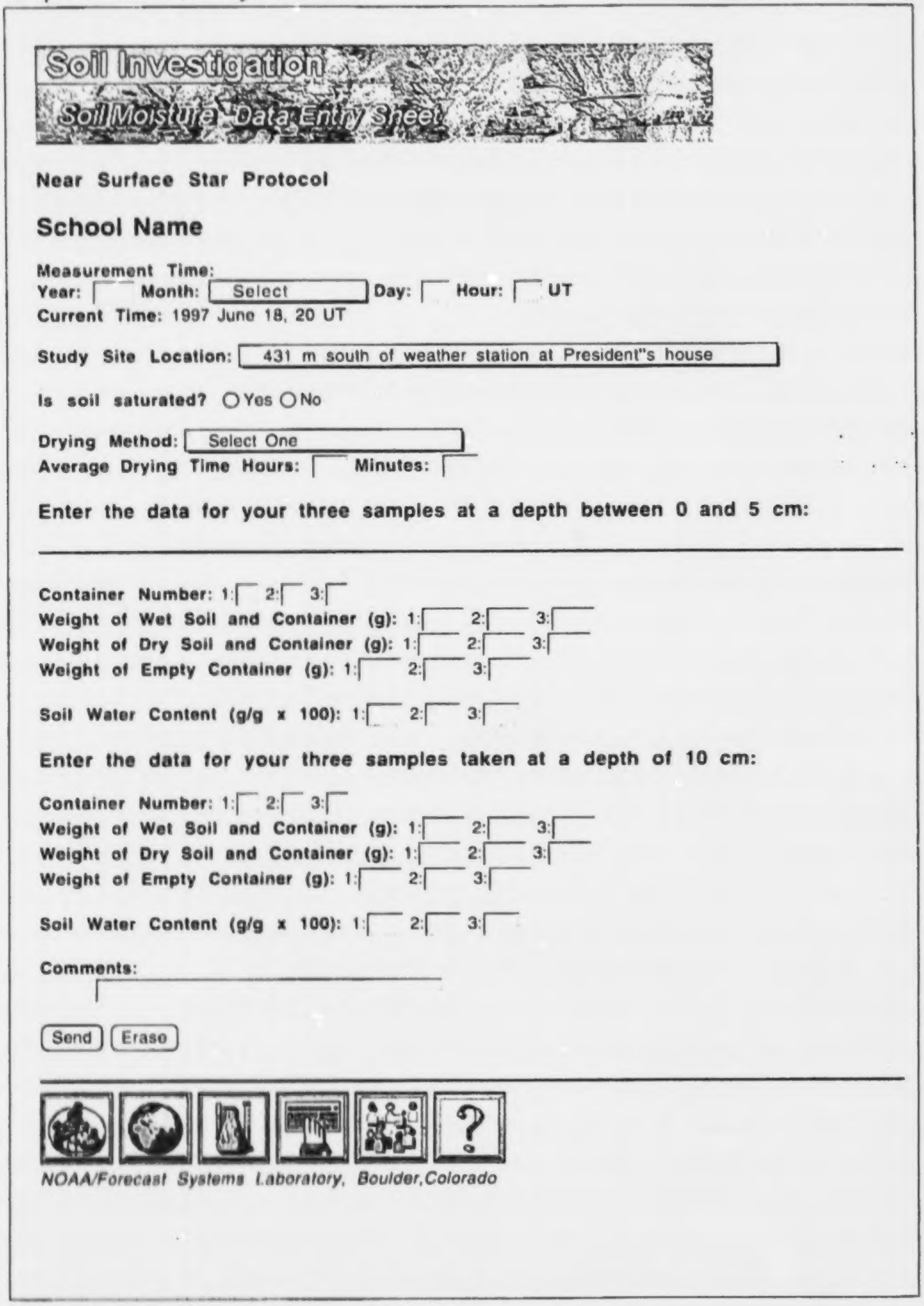
Sample GLOBE Data Entry Screen



Soil Investigation

Soil Moisture Data Entry Sheet

Near Surface Star Protocol

School Name

Measurement Time:
Year: ☐ **Month:** Select **Day:** ☐ **Hour:** ☐ **UT**
Current Time: 1997 June 18, 20 UT

Study Site Location: 431 m south of weather station at President"s house

Is soil saturated? ○ Yes ○ No

Drying Method: Select One
Average Drying Time Hours: ☐ **Minutes:** ☐

Enter the data for your three samples at a depth between 0 and 5 cm:

Container Number: 1: ☐ 2: ☐ 3: ☐
Weight of Wet Soil and Container (g): 1: ☐ 2: ☐ 3: ☐
Weight of Dry Soil and Container (g): 1: ☐ 2: ☐ 3: ☐
Weight of Empty Container (g): 1: ☐ 2: ☐ 3: ☐

Soil Water Content (g/g x 100): 1: ☐ 2: ☐ 3: ☐

Enter the data for your three samples taken at a depth of 10 cm:

Container Number: 1: ☐ 2: ☐ 3: ☐
Weight of Wet Soil and Container (g): 1: ☐ 2: ☐ 3: ☐
Weight of Dry Soil and Container (g): 1: ☐ 2: ☐ 3: ☐
Weight of Empty Container (g): 1: ☐ 2: ☐ 3: ☐

Soil Water Content (g/g x 100): 1: ☐ 2: ☐ 3: ☐

Comments:

NOAA/Forecast Systems Laboratory, Boulder,Colorado

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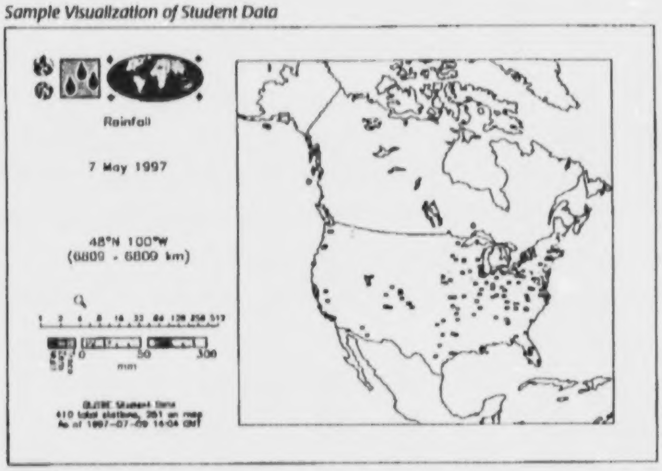
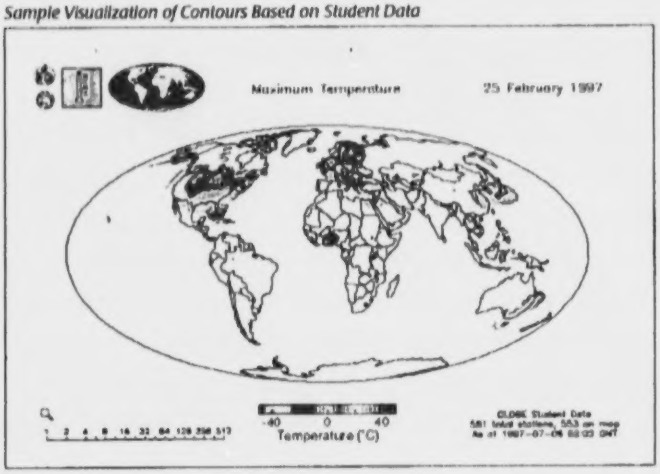
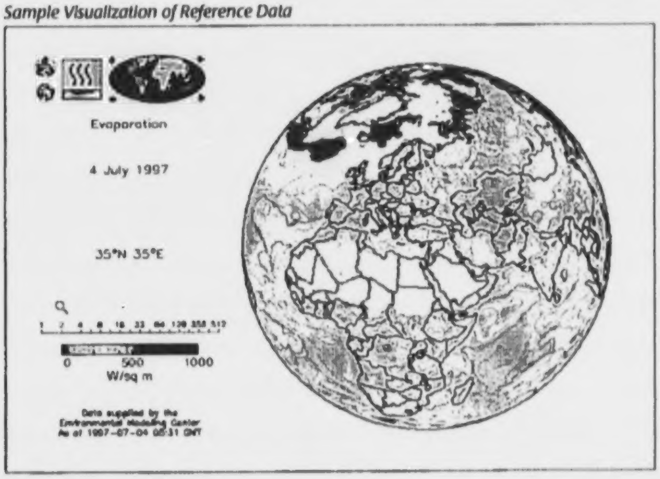
Sample Visualization of Student Data


Rainfall
7 May 1997
48°N 100°W
(6809 - 6809 km)
1 2 4 8 16 32 64 128 256 512
0 50 300
mm
GLOBE Student Data
410 total stations, 261 on map
As of 1997-07-09 14:04 GMT

Sample Visualization of Contours Based on Student Data


Maximum Temperature
25 February 1997
1 2 4 8 16 32 64 128 256 512
-40 0 40
Temperature (°C)
GLOBE Student Data
581 total stations, 553 on map
As of 1997-07-06 02:03 GMT

Sample Visualization of Reference Data


Evaporation
4 July 1997
35°N 35°E
1 2 4 8 16 32 64 128 256 512
0 500 1000
W/sq m
Data supplied by the
Environmental Modeling Center
As of 1997-07-04 05:31 GMT

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Remote Sensing

Introduction

All of us perceive the environment with our senses. Some senses require us to come in contact with what we are sensing - we touch and taste. Some senses allow us to perceive objects at a distance - we see and hear. In this second case, we are sensing objects or phenomena that are remote from our eyes or ears - we are doing remote sensing. By using the microscope, telescope, camera and film, microphone, amplifier, and speaker, and video camera and television we expand our remote sensing capabilities. These technologies allow us to see farther, to observe finer details, and to perceive fainter signals than our unaided senses.

Our remote sensing capabilities come in a mobile package complete with an energy source and data processing and storage facilities - we turn our heads to gaze in different directions, move to get a better view or to hear more clearly, make decisions based on what we sense, and remember sights and sounds. To see more of the environment around us, we can climb a ladder, a tree, or a hill and gain a wider view. Until the advent of hot-air balloons in the last century, these were the only ways for humans to get a bird's eye view of the Earth. With the invention of cameras in the mid-1800s, people began to make aerial photographs from balloons. One of the first balloon photographs was of Boston, Massachusetts, USA, taken in 1860 from 1200 feet above the city. A particularly intriguing photograph was taken of the 1906 San Francisco earthquake and fire using an array of 17 kites moored to a boat anchored in San Francisco Bay!

Prior to 1960, the most widely used remote sensing systems were based on the camera, although infrared film and radar had been developed and used during World War II. Space-based remote sensing began in 1960 with the launch of the first Television Infrared Observation Satellite (TIROS I). The TIROS series of satellites initially focused on providing images of clouds and were the predecessors of the present National Oceanic and Atmospheric Administration (NOAA) polar-orbiting weather satellites. The first remote sensing satellite focused on the land surface was the Earth Resources Technology Satellite (ERTS I) launched by the National Aeronautics and Space Administration (NASA) in July 1972. Later, this satellite was renamed Landsat I, and became the first of a series of Landsat satellites designed to image and map land surface features. Today, there are dozens of environmental satellites launched and operated by various countries and multinational organizations.

Initially, the costs associated with these technologies restricted their use to large government and private organizations. More recently, the power of desktop computing and the proliferation of satellites from many countries have opened this frontier to people everywhere. Now, small colleges and businesses, elementary and secondary schools, land planners, environmental groups, and even individuals make use of satellite remote sensing technology.

Various images derived by remote sensing techniques appear throughout this guide. Some look like photographs – indeed some are photographs. The *Blue Marble*, perhaps the most famous image of the Earth from space, is a photograph taken by Apollo 17 astronauts on their journey to the Moon in December 1972. See

Figure IMP-I-1. Other images may look to you like abstract paintings. Today, most remote sensing images are not photographs; they are digital images sensed on solid-state detectors and converted to numbers which are transmitted, stored, and displayed by computers. The remote sensing instruments on Landsat produce this type of digital image. Wherever possible, each GLOBE school is provided with an image of its GLOBE Study Site taken from a Landsat satellite by an instrument named Thematic Mapper (TM).

Figure IMP-I-1: The Blue Marble–Photograph taken from Apollo 17, December 1972

Source: NASA

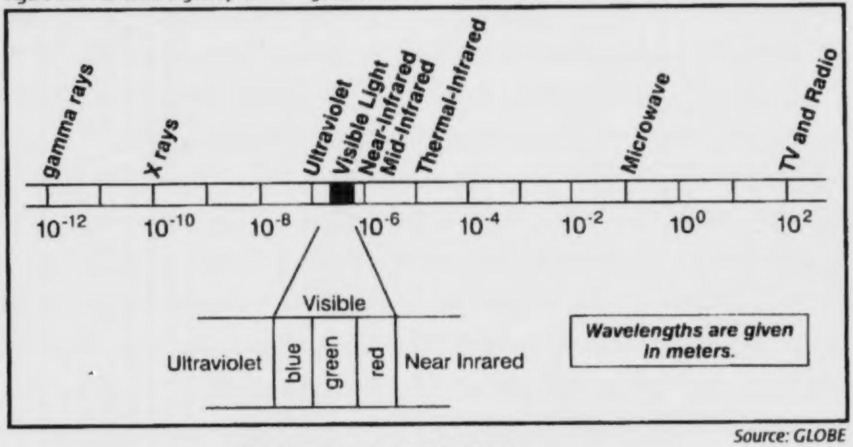
What Properties of a GLOBE Study Site Does the Thematic Mapper Measure?

The TM's sensors record visible and infrared (IR) sunlight that is reflected from the Earth outward into space. Thematic Mapper also includes sensors that detect IR radiation or light that is emitted by the Earth, but this part of TM's capabilities are not used in GLOBE.

Visible light is *electromagnetic radiation* or *light waves* that can be detected by our principle remote sensing capability, the human eye. It is said that the human eye provides us with about 90% of the information we receive about our environment. Visible light, however, is only a small part of a very large continuum of light waves. See Figure IMP-I-2. This radiation forms a continuous spectrum in which the differing waves are characterized by their wavelengths. Wavelengths are commonly measured in one of two units, the micron (micrometer, μm), where 1 μm = 1 x 10^{-6} m (0.000001 m), or the nanometer (nm) where 1 nm = 1 x 10^{-9} m (0.000000001 m). The shortest wavelengths are associated with gamma rays, whose wavelengths are about 10^{-6} μm, while at the long end of the scale, radio and TV waves have wavelengths of 10^{+8} μm (=100 meters). Visible light lies close to the middle of this spectrum with violet light being the shortest wavelength, and red light the longest. Measured in nanometers, the wavelengths of visible light range from 400 nm for violet to 700 nm for red.

On either side of the wavelength *band* of visible radiation are other wavelengths of value in remote sensing. At wavelengths just longer than visible light are the three bands of infrared light–near, middle, and thermal. The image of the GLOBE

Figure IMP-I-2: Wavelengths of Electromagnetic Radiation



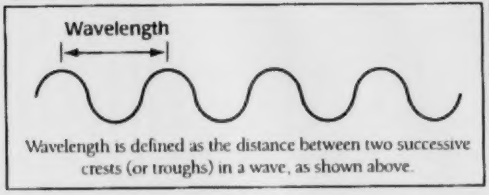
Source: GLOBE

Wavelengths of visible light:

Blue visible light: 4.5 x 10^{-7} meters
Green visible light: 5.5 x 10^{-7} meters
Red visible light: 6.5 x 10^{-7} meters

The labeled wavelengths in the electromagnetic spectrum diagram are the center of a range (or band) of wavelengths for that type of wave. The types of waves are not clearly separated. Think about a rainbow with its bands of red, orange, yellow, green, blue, and violet light. The colors of the visible light waves blend into one another. For our purposes, we will use the labeled wavelength (center of the range) in the diagram.

Figure IMP-I-3: Wavelength



Wavelength is defined as the distance between two successive crests (or troughs) in a wave, as shown above.

When you think of wavelengths of radiation you can think of ocean waves. Wavelengths are measured from the crest of one wave to the crest of the next. Think of waves you have seen on lakes or the ocean. How far apart were the crests of those waves?

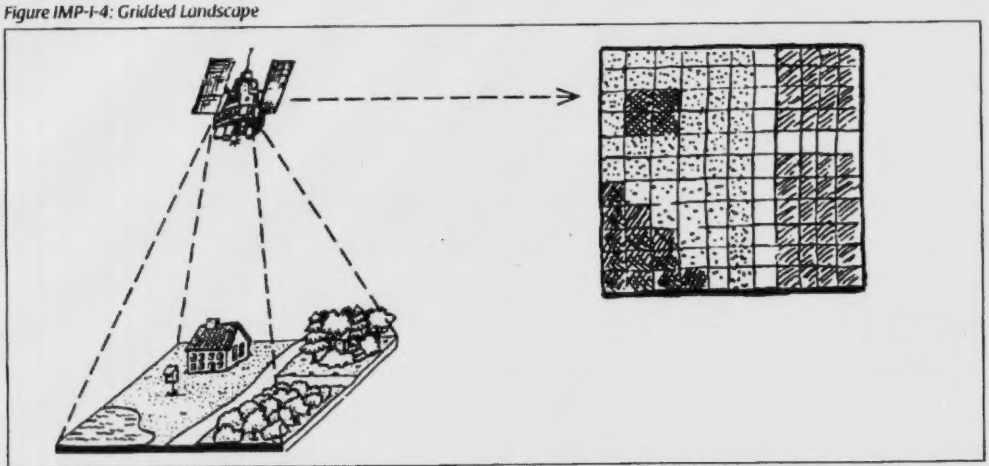
Study Site is provided in TM's three visible bands (blue, green, and red), one near IR band, and one of its two middle IR bands. These visible and infrared data are used to assess extent and the health of crops, forests, and other forms of vegetative cover.

In each band, the TM measures the intensity of light reaching its detector from a specific place on the Earth and records this intensity as a number ranging from 0 to 255. In the binary or base 2 system of counting, it takes eight digits or places to count up to 255 and since each binary digit is referred to as a bit, TM is said to provide eight-bit data. The detectors and optics of TM were constructed so that from the 705 km orbital altitude of Landsat, the specific place reflecting light into an individual detector is 30 m by 30 m on the Earth's surface. Because of this, TM is described as having a spatial resolution of 30 m. Objects on the surface which are smaller than 30 m will be averaged together with their surroundings in the intensities measured and cannot be directly seen in a TM image.

Satellite Images

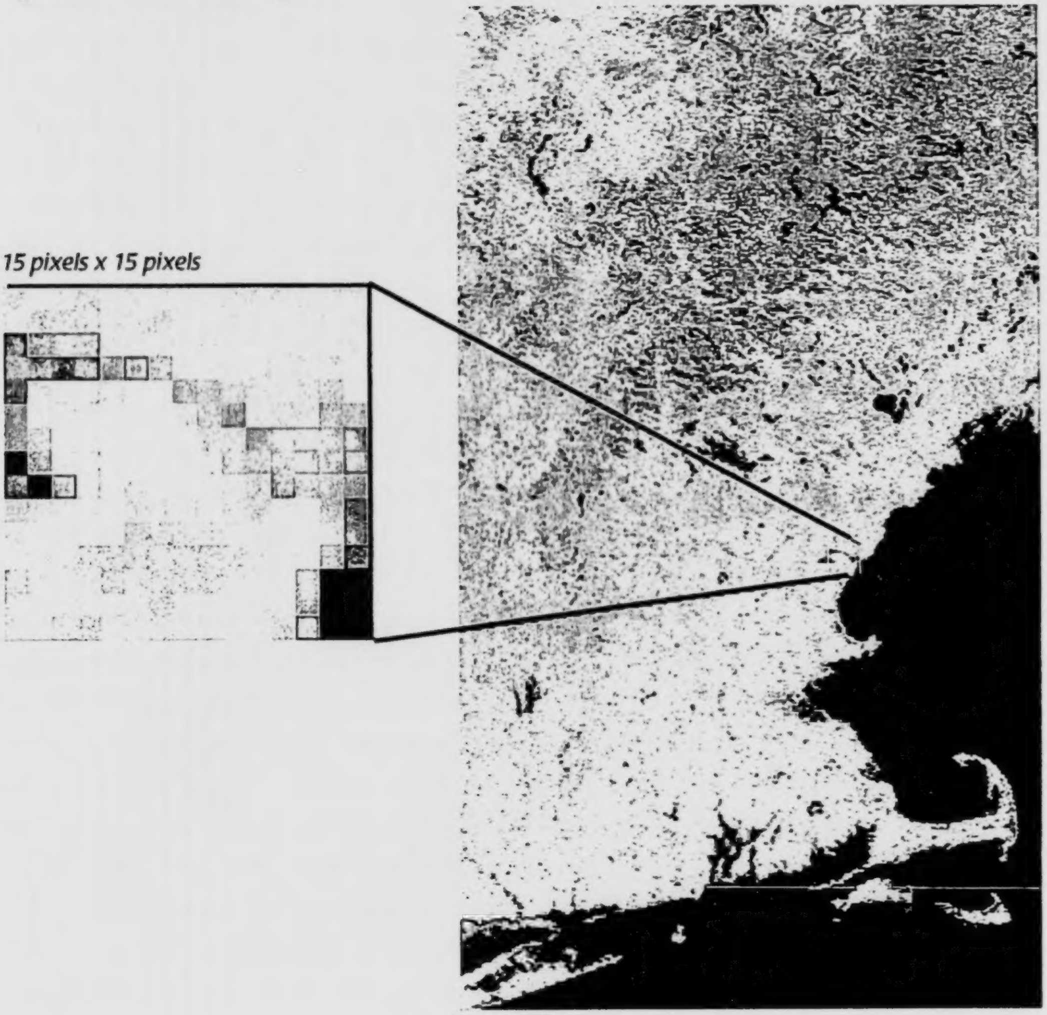
A picture of a large area of the Earth's surface can be produced by assembling the intensities measured for many adjacent 30 m by 30 m areas. If you look at a computer or television screen or at a pictures in a newspaper or comic book through a magnifying glass you will see small individual dots of color. Our eyes normally see this array of dots as a continuous image. Each of the dots is a picture element or pixel. To produce a digital image using TM data, a computer uses each intensity value to determine the brightness of one pixel on its screen. When fully displayed, each pixel in an image on the computer screen corresponds to a particular location on the Earth. This concept can be observed in the *blockiness* that is apparent when one blows up or zooms in to view a digital image more closely. See Figure IMP-I-5.

Figure IMP-I-4: Gridded Landscape



This represents how a satellite views the earth's land cover as a group of equal size units placed on a landscape. Each unit is called a pixel. Source: Jan Smolik 1996 TEREZA Association for Environmental Education, Czech Republic

Figure IMP-I-5: AVHRR Image



Source: NASA

A false color infrared image of New England from the Advanced Very High Resolution Radiometer (AVHRR) sensor aboard a NOAA polar orbiting satellite. Each pixel in this scene is approximately 1.1 km on a side. The enlarged section shows a 15 pixel by 15 pixel area which is roughly the size as a GLOBE Study Site and which includes roughly the same section of Portsmouth, N.H., as Figures IMP-I-6 through IMP-I-9. The brightest pixels in this enlarged section represent the runway and apron area used to park aircraft and service vehicles

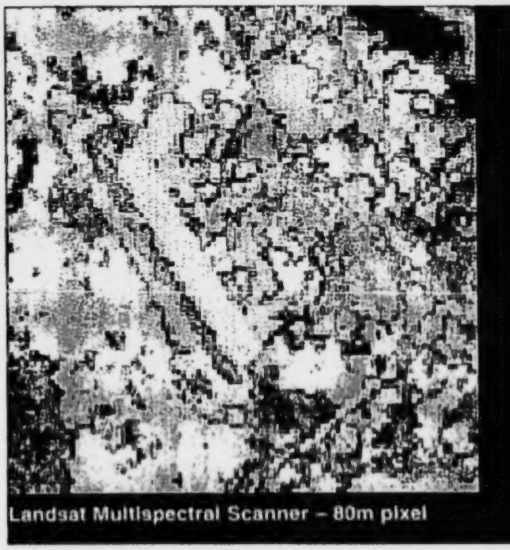

Landsat Multispectral Scanner – 80m pixel

Figure IMP-I-6

This Landsat Thematic Mapper image shows the same area as Figure IMP-I-4 with the 80 m resolution Multispectral Scanner flown aboard the first five Landsat satellites. In this view, the parking area is seen, but few other ground details are visible.

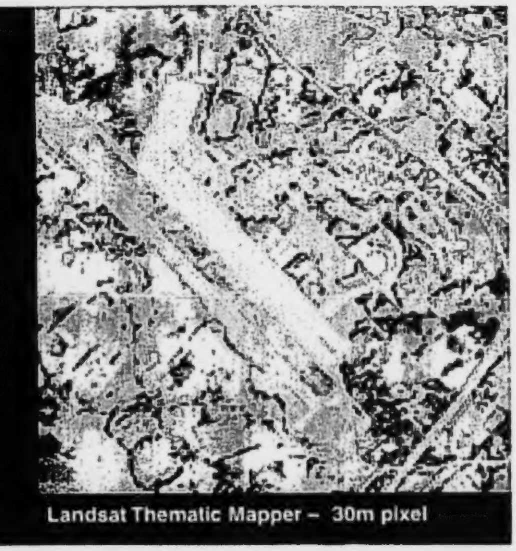

Landsat Thematic Mapper – 30m pixel

Figure IMP-I-7

The Landsat Thematic Mapper image of the same area as Figures IMP-I-4 and IMP-I-5 with 30 m. In this view, main roads are visible. These data have a high enough resolution to see features as small as a house. They are preferred for many types of ecological and environmental studies as they have both high spatial and spectral resolution.

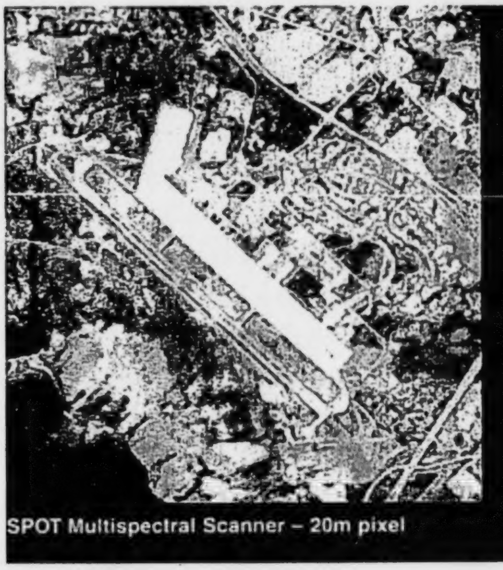

SPOT Multispectral Scanner – 20m pixel

Figure IMP-I-8

Pease, N.H. at the 20 m resolution of the French SPOT satellite's Multispectral Scanner. In this view, secondary roads and structures can be seen.

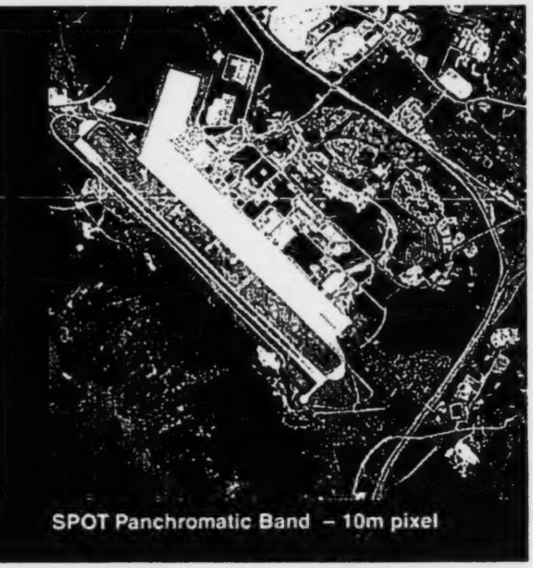

SPOT Panchromatic Band – 10m pixel

Figure IMP-I-9

Pease, N.H. at the 10 m resolution of the French SPOT satellite's Panchromatic Imager.

Source: Used with permission of the Earth Day Forest Watch Program, University of New Hampshire, Dr. Barry Rock and Mr. Gary Lauten

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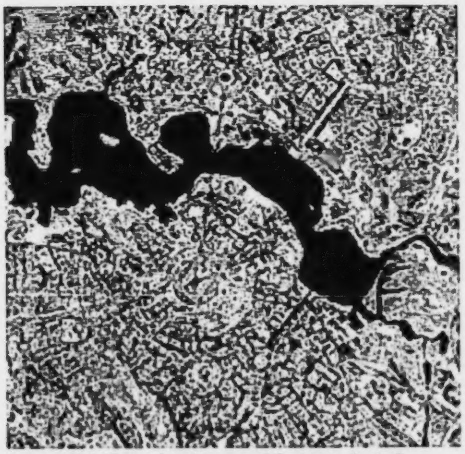


Figure IMP-I-10: Land-water area of Canberra, Australia, viewed in the near-infrared band only. Note that the water appears black. Source: EROS Data Center

Figures IMP-I-6 through IMP-I-9 show several satellite views of approximately the same area, the Pease International Tradeport in Portsmouth, New Hampshire, USA at several different spatial resolutions to demonstrate the effect of pixel size on image quality.

As the size of a pixel decreases, the amount of information needed to make an image of the same size area on the ground increases. Limitations in computer storage can make it impractical to use high resolution data when studying very large areas. The purpose of an investigation must therefore be considered when deciding which satellite or other remote sensor(s) to use. For GLOBE the 30 m by 30 m pixel size of Landsat is most appropriate. With this pixel size, the 15 km by 15 km area of a GLOBE Study Site can be covered by an image of 512 pixels by 512 pixels. Storing each TM band of such an image requires 256k bytes of memory and five bands fit nicely on a single floppy disk.

Our eyes can see in color as well as in black and white. If only one band of TM data is used to construct an image, it can be fully represented using 256 different shades of gray which our eye perceives as amounts of brightness. See Figures IMP-I-9 and IMP-I-10. The full range of colors we see can be produced by combining light of three different colors, for instance red, green, and blue on a computer screen or yellow, red, and blue when mixing paints. See Figure IMP-I-11. On the computer screen or on a printed image, each pixel is produced by a combination of red, green, and blue. This allows us to view images of three different bands of TM data simultaneously. If we let the intensity of the red band of TM determine the amount of red in the corresponding pixel, the green band determine the amount of green, and the blue band the amount of blue, the resulting image will closely resemble what our eye would see looking down at the Earth's surface and is referred to as a visible image. Alternatively, the red portion of each pixel can be determined by the intensity of near IR light detected by TM, the green determined by the intensity of red light, and the blue determined by the intensity of green light to produce a *false color infrared* image roughly corresponding to IR sensitive camera film. Figure IMP-I-12 shows such an image of a land and water area in Prague, the Czech Republic. Other band combinations are also possible, but in each case we are limited by the capability of our eyes to seeing at most three bands of TM in a single image.

Spectral Patterns

Let's consider what the different colors mean. When white sunlight (comprised of all colors) is incident on an object, some of the colors are absorbed and others are reflected. For example, an object that appears red is reflecting red light while absorbing all other colors. See Figure IMP-I-13. If all incident light is reflected, the object appears white, whereas if all the light is absorbed, the object appears black.

The key to interpreting multispectral data is understanding the reflectance properties of different surfaces or objects viewed by the sensor. The tendency of an object to reflect or absorb solar radiation at different wavelengths gives rise to its *spectral pattern*. See Figure IMP-I-11. Just as a person can be identified by his or her picture, spectral and spatial patterns can be combined to identify a remotely sensed object or surface feature. We can predict the spectral patterns of objects within the range of visible light, since this is the spectral region that we see. For example, we would predict the ocean to have a higher reflectance in blue spectral bands and the ocean appears blue in a visible image because most of the light entering the ocean is absorbed, while only the blue light is reflected. We would expect vegetation to have high reflectance in green because leaves are green, and so forth.

TM is not limited to detecting only in the visible range. Scientists have learned to interpret reflectance patterns outside the visible spectral region, and, in many instances, it is this invisible information that accounts for the power of multispectral imagery. Near infrared (NIR) radiation is almost completely absorbed by water, whereas land and particularly vegetation have high reflectance in the NIR region. Thus, the NIR bands are useful in differentiating land and water. In addition, the NIR bands are useful in locating and identifying different species of vegetation, and in determining whether or not particular plants healthy or diseased. Middle infrared (MIR) bands are sensitive to moisture content and, therefore, they are also useful in vegetation studies.

Satellite Orbits and Instruments and the Timing and Frequency of Observation

Another important aspect of satellite remote sensing is the frequency of coverage, that is, how often the satellite passes over a location on the Earth's surface. This is determined by the orbit in which the satellite is placed and the width of the area it images on the Earth's surface. The higher

Figure IMP-I-11: Reflectance of Some Targets

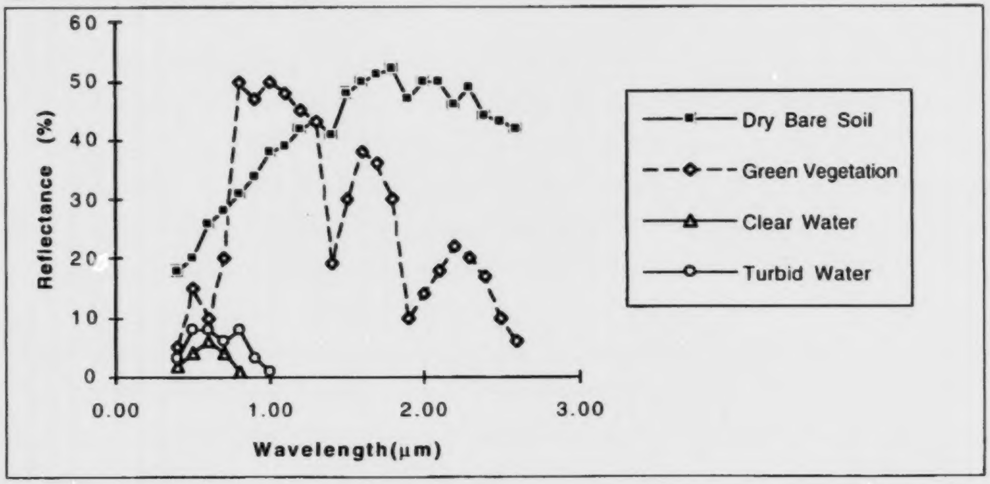
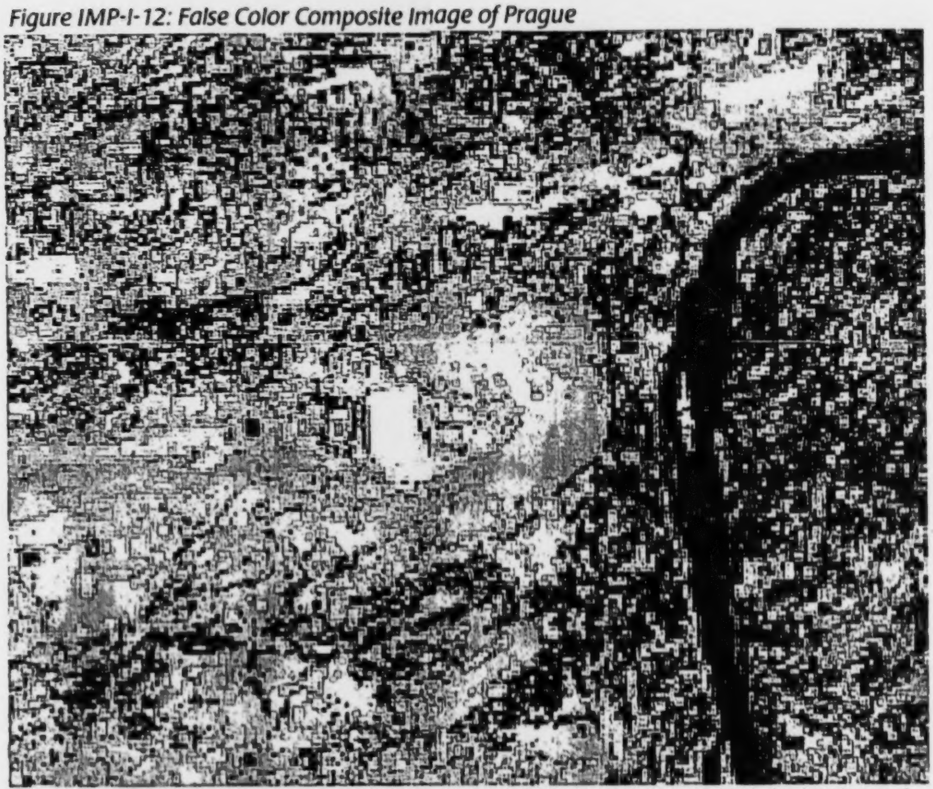
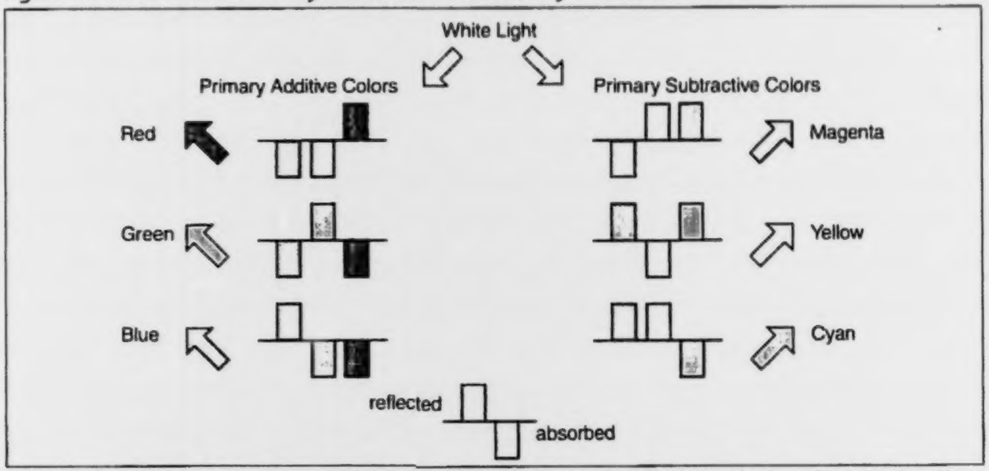


Figure IMP-I-12: False Color Composite Image of Prague



A false color composite image of part of the city of Prague, in the Czech Republic. Water appears black, developed areas of white to gray, and vegetated areas red. Source: EROS Data Center

Figure IMP-I-13: Visual Primary Additive and Secondary Subtractive Colors



White Light
Primary Additive Colors
Primary Subtractive Colors
Red
Green
Blue
Magenta
Yellow
Cyan
reflected
absorbed

Additive Primary and Secondary colors are produced when objects absorb and reflect different combinations of the colors found in white light. Source: GLOBE the orbital altitude, the longer the time required for the satellite to orbit the Earth. As a general rule, the smaller the size of the pixels in a remote sensing instrument, the narrower its field of view. The orbit of Landsat and the width of the TM image area were chosen to provide coverage of every place on the Earth's surface at least once every 16 days (except for small regions surrounding the poles which are never imaged).

The orbit was also chosen so that Landsat always passes overhead at the same local time each day. At the equator this time is about 9:45 am. Such orbits are called sun-synchronous. Sun angles, shadows and other such effects visible in TM images remain similar or vary slowly in predictable ways.

As the Earth progresses through the seasons, the reflectivity of the land surface changes principally due to changes in vegetation and the distribution of snow cover and sea ice. The changes in vegetation occur slowly as a result of seasonal changes in deciduous plants and the amount of moisture available to plants resulting from seasonal precipitation patterns.

Implications for the Planet

Although the science of remote sensing has evolved steadily since the first Earth observing satellites, the challenges of interpreting remote sensing data remain large. Satellite images are far more complex than simple photographs. An image based on multispectral data involves measurements of reflected or emitted radiation in several bands. Because human experience is limited to visible sunlight, we have no intuitive knowledge of how features on Earth respond to other forms of electromagnetic radiation. We must rely on experiments, often involving ground-based measurements and airborne instruments, to learn how various features will reflect or emit radiation in different regions of the spectrum.

With satellite images, the possibility of monitoring and analyzing critical environments anywhere in the world is greatly expanded. Ecologists can study natural and human-induced changes in land use patterns and the global distribution of major *biomes*. Atmospheric chemists can relate these changes to increases in greenhouse gases, and oceanographers can study physical, chemical, and biological processes at the atmosphere-ocean interface (i.e. the sea surface). Students, too, can gain valuable insights into the nature of their own environment and share these with students from around the world.

Winston Churchill is credited with having said that the farther away from something one gets, the farther into the future one sees. With remote sensing images, students worldwide can step back into space, and view their home as a whole - a self-contained life-support system powered by the sun. How fast can it, has it, and will it adapt to changes of various sizes, and what are the consequence for our communities? By viewing the Earth with satellite images and developing an understanding of them, all of us are gaining an appreciation of our connection to ecosystems both local and global.

Selecting Your GLOBE Study Sites

Initial Considerations

The selection of the local study and sample sites can be an opportunity to begin an inventory of the area around the school, and to discuss criteria for measurement sites. What is a good place to measure water temperature, and why? What do you have to consider when planning where to dig a soil profile? Where can you get representative samples of soil moisture, and what might influence the choice of sampling strategy? How can my Landsat imagery help me with these decisions? These are only a few of the multiple questions that can serve as catalysts for learning.

For each measurement site within your GLOBE Study Site there will be hard choices to make because no one will have a perfect set of locations. This is an opportunity to work on solving problems with your students in order to come up with the best arrangement for your class, your school, and your schedule. We suggest you try to come up with several candidates for site selection and have your students be active participants in the selection process.

GLOBE Study Site

Your GLOBE Study Site is the 15 km by 15 km area centered on your school. All of the smaller study sites are located within this large GLOBE Study Site. GLOBE working with the Country Coordinators will provide a Landsat Thematic Mapper (TM) scene of this area. From an instructional standpoint, the goal of these sites is to give your students a feel for the physical resolution of satellite images as well as providing a suitable and convenient area upon which to focus student measurement activities.

Within your 15 km x 15 km GLOBE Study Site, you will select several specific study sites, corresponding to the individual protocols: Atmosphere, Hydrology, Soil Moisture, and Land Cover/Biology as detailed below. Once established, these study sites are locations to which students will return again and again to take measurements. The Land Cover and Soil Characterization protocols involve measurements which are done only once at specific locations which are referred to as sample sites.

Using the GPS Receiver to Determine the Location of Your School and Sites

The GLOBE Program owns GPS receivers which are maintained by the University Navstar Consortium (UNAVCO). To borrow a GPS receiver, U.S. schools should direct their requests to UNAVCO. Country coordinators may request to borrow GPS receivers from UNAVCO for use by their GLOBE schools. For more details, refer to the GPS Investigation.

Atmosphere Study Site

In the Atmosphere Study Site, your students will measure temperature, precipitation, cloud type, and cloud amount. Since these are daily measurements, your Atmosphere Study Site should be located on or near your school grounds, so that students will have easy daily access to the instruments. However, there are some special siting considerations as detailed below.

1. Measurements of cloud amount and cloud type require an unobstructed view of the sky. The middle of a sports field or parking lot is an excellent location.
2. For measurements of precipitation, the rain gauge (and snowboard) must be in an open area with a natural (e.g. grassy) surface. Do not place the rain gauge close to buildings, trees or high bushes, which can affect the amount of rain that collects in the rain gauge. An open field, a playground, or the side of a sports field would be good locations for the rain gauge. The snowboard should also be placed in an open area, away from buildings, with special care to select a place where snow shoveling will not pile snow onto or clear snow from the board.
3. For measurements of temperature, you need to put the thermometer in a small standardized, protective shelter. This shelter, painted white, with slats on the sides to let air circulate, is mounted on a post. The shelter has a door, enabling

students to look in to read the temperatures. As with the rain gauge, the instrument shelter should be in an open area with a natural (e.g. grassy) surface, away from buildings, trees or high bushes.

If possible, place the rain gauge within 100 meters of the Soil Moisture Study Site (see below), as the rain data will help students and scientists better understand the soil moisture data. Also, closeness will facilitate students taking weekly soil temperature measurements at the same time that they collect atmosphere data.

Some schools cannot meet all these criteria for locating their Atmosphere Study Site. GLOBE encourages such schools to describe carefully all the ways in which their site differs from the criteria given in this guide and to report this information on the Atmosphere Study Site Definition Data Entry Sheet. For more details, refer to the Atmosphere Investigation.

Hydrology Study Site

Water characteristics will be measured in your GLOBE Study Site, at a body of water, such as a lake, river or stream. There are two steps to selecting your Hydrology Study Site. First, you need to determine which bodies of water (streams, rivers, lakes, bays, the ocean, ponds, and reservoirs) are in your GLOBE Study Site. You can determine this from local maps or from the Landsat image of your GLOBE Study Site. Second, you need to select one that is most appropriate for the Hydrology Investigation.

Ideally, the Hydrology Study Site should be within the major watershed of the 15 km by 15 km GLOBE Study Site, and connected to water systems that flow into larger river or estuary systems. This means that if your site includes more than one watershed, you have to figure out which one is most important. Within this watershed, select a specific site where the hydrology measurements (water temperature, dissolved oxygen, nitrate, pH, alkalinity, turbidity, and either conductivity or salinity) will be taken.

If the selected study site is a moving body of water (i.e. stream or river), locate your sampling site at a riffle area as opposed to still water or rapids. This will provide a more representative measurement of the water in the stream or river.

If the selected study site is a still body of water (i.e. a lake or reservoir), find a sampling site near the outlet area or along the middle of the water body. Avoid inlet areas. A bridge or a pier are good choices. If your water body is brackish or salty, you will need to know the times of high and low tide at a location as close as possible to your study site.

Hydrology measurements should be taken weekly, and therefore it is important that your study site be easily accessible to students on a routine basis. A site which is ideal from a science perspective but where transportation problems prevent students from taking measurements regularly is not as good as an acceptable site whose location is conducive to routine observations.

Soil Study and Sample Sites

For the Soil Investigation, there are two types of sites: Soil Characterization Sample Sites and a Soil Moisture Study Site.

At Soil Characterization Sample Sites, holes will be dug to expose the soil profile and permit the collection of soil samples and the examination of the various soil layers or horizons. One site should be located within the Biology Study Site in order to link the soil type with land cover characteristics. A second site should be located as close as possible to the Soil Moisture Study Site. In this way, the soil properties needed to interpret soil moisture measurements can be determined.

At Soil Moisture Study Sites, either of two soil moisture measurement techniques may be employed. The first uses a technique called *gravimetric sampling* and simply involves collecting soil samples and drying them to determine their moisture content. Samples are collected 12 times during a year, and the timing and pattern of collection are chosen by you and your students from a set of options described in the Soil Investigation. The second, which is optional and only recommended for advanced students in areas where the soil is not acidic, involves burying gypsum block moisture sensors at four specified depths in the soil and collecting readings from

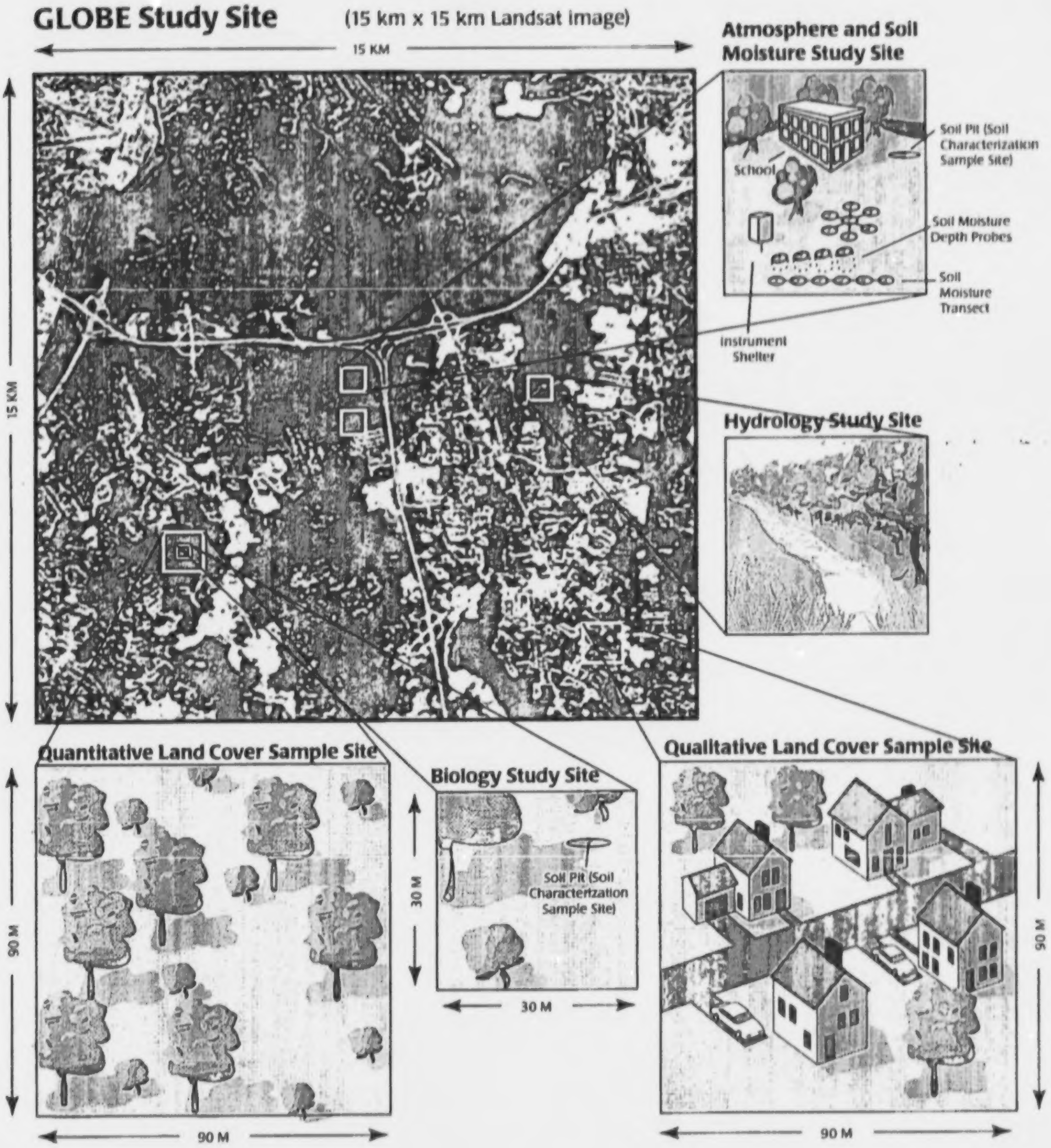


Figure IMP-I-14: The Relations of GLOBE Study Sites

GLOBE Study Site
(15 km x 15 km Landsat image)
15 KM
15 KM
Atmosphere and Soil Moisture Study Site
School
Soil Pit (Soil Characterization Sample Site)
Soil Moisture Depth Probes
Soil Moisture Transect
Instrument Shelter
Hydrology Study Site
Quantitative Land Cover Sample Site
90 M
90 M
Biology Study Site
Soil Pit (Soil Characterization Sample Site)
30 M
30 M
Qualitative Land Cover Sample Site
90 M
90 M

the sensors on a daily basis. Wires extend from the buried blocks to the surface, and to take a reading, you connect a meter to each pair of wires in turn.

The time it takes water to infiltrate the soil and the near-surface soil temperature are measured at the Soil Moisture Study Site. The timing and sampling pattern for these observations along with the details on all soil measurements are described in the Soil Investigation.

To enable correlation of the atmosphere data with the soil moisture and temperature data, a Soil Moisture Study Site must be located within 100 m of the rain gauge in the Atmosphere Study Site. This results in there being a single Atmosphere and Soil Moisture Study Site as shown in Figure IMP-I-14. Throughout the rest of the guide the two sites are referred to individually. If this collocation is not possible, a second rain gauge can be placed at the Soil Moisture Study Site and monitored during the period in which Soil Moisture measurements are being collected to provide the needed data on moisture input to the soil. These precipitation data can be reported to GLOBE by defining a second Atmosphere Study Site at which only the precipitation data are collected and reported. Soil temperature data can be collected at the Atmosphere Study Site throughout the year and at the Soil Moisture Study Site during the period in which soil moisture measurements are being collected to provide data for correlation with both soil moisture and atmospheric temperature.

Land Cover/Biology Study and Sample Sites

In the *Land Cover/Biology Investigation* students monitor the changes in vegetation at a Biology Study Site and characterize the land cover of the GLOBE Study Site by making observations at a number of Land Cover Sample Sites. The data from these sample sites are compared with the Landsat data and images of your 15 km by 15 km GLOBE Study Site to determine the accuracy of the satellite observations. This accuracy assessment is done by scientists and can be done by your students as well.

Land Cover Sample Sites, which are used to document land cover characteristics, are 90 m by 90 m in size. The site must be in an area with similar (homogeneous) cover. These characteristics are needed to enable verification of satellite data. There are two types of land cover sites. In areas of forest, woodland, and grassland, extensive measurements can be made of the vegetation; if these data are collected, these sites are Quantitative Land Cover Sample Sites. If these vegetation measurements are not made at the forest, woodland, or grassland sites, then they are Qualitative Land Cover Sample Sites. In other areas, the type of cover is determined only by observation because currently there are no extensive GLOBE vegetation measurement protocols for these cover types. These sites are also Qualitative Land Cover Sample Sites.

As you have time (perhaps over several years) your students should observe at least one Land Cover Sample Site for each major type of land cover found within your GLOBE Study Site. In GLOBE, land cover is classified using the Modified UNESCO Classification (MUC) found in the *Land Cover/Biology Investigation*.

Your Biology Study Site is a 30 m by 30 m area of natural vegetation. All new Biology Quantitative Study Sites must be located within one of the Land Cover Sample Sites. Biometry measurements are made once or twice each year — in the growing season and in the adverse season if there is one, and so access to the site is less of an issue than for sites of more frequent measurements. Students can practice biometry observations at a location adjacent to the school.

For further information on setting up these Land Cover and Biology Sites, see the *Land Cover/Biology Investigation*

How to Teach a Protocol

When you teach your students a new protocol, we recommend that you use the following steps. This procedure, with minor modifications, can be used to teach students nearly all of the GLOBE protocols.

Good education = good data = good science. If you do a good job teaching the protocol, then your students will submit good data. If they submit good data, then you can extend the learning opportunities by having your students analyze their own data and data from other schools. This in turn helps them better understand the science domain and get even better at their measurements.

In this overview we use water temperature as the example to help you understand this process.

Phase 1 - Getting Ready

Students read the Letter from the Scientist - At the beginning of each investigation is a personal letter from the GLOBE scientists who are leading the investigations. Copy the letter and distribute it to your students. When they read this letter, your students start to make a personal connection with the scientist(s). If you cannot copy the letter, make it available to your students in some other way.

Example - Martha Conklin and Roger Bales are the scientists for the *Hydrology Investigation*. Together, they wrote the letter to the students.

Students read the Interview with the Scientist(s) - Immediately following the letter from the scientist(s), is an interview in which the scientist(s) talk about their background, their work as scientist(s), and why they need your data. Also, the interview contains interesting anecdotes to further personalize the scientists.

Example - In their interview, Martha Conklin and Roger Bales discuss how they first became interested in science, the nature of their work as hydrologists, and what they will investigate using the GLOBE student data.

What are you measuring? - Through use of GLOBE learning activities, discussions, or field trips, you need to make sure your students understand the basic concepts included in the protocols they are performing. In reality, your students may not really understand the concept until they are fully engaged with the measurement process. However, at this stage they at least need to have an introduction to the concepts.

Example - Water temperature varies from one location to another and at different times of the year.

Phase 2 - Selecting the Study Site

Understand the guidelines for selecting the study or sample site for this measurement - Every protocol includes some carefully prepared guidelines on the selection of the study or sample site for each measurement. Review these with your students. In this *Implementation Guide* there is a comprehensive overview of the criteria for all study and sample sites to help you in this process.

Students practice measuring canopy cover for the Land Cover/Biology Investigation.

Example - The Hydrology Study Site should be a stream, river, lake, reservoir, bay, ocean, or pond within your 15 km x 15 km GLOBE Study Site.

Select the study or sample site. Based on maps of your region, the Landsat image, personal familiarity with the region and/or a field trip with your students, select the study or sample site. Review the criteria to be sure that the site matches the criteria. Convenience to your school is generally helpful in selecting study sites which should remain the same from year to year.

Example - You and your students select the Meadowbrook stream, which is in the woods a short walk from your school.

Visit the study site. If possible, take your students on a field trip to observe the study site and think about its characteristics and environment.

Example - Meadowbrook stream is a shallow stream about 5 m wide surrounded by trees and flowing down from Mountainview Hill.

Phase III - Learning and Practicing the Protocol

Introduce the instrument. Most protocols use some type of special instrument(s) to do the measurement. Show the instrument(s) to the students. Explain as well as possible how it works. Your students may not fully understand how it works until they have experience using it.

Example - A thermometer is used to measure temperature.

Demonstrate the protocol. Following the procedures detailed in the protocol, demonstrate the steps of the protocol. In most cases, you can do this demonstration in the classroom. Write the steps of the protocol on the board or on a sheet of poster paper for students to follow along.

Example - To demonstrate the water temperature protocol, use tap water in the classroom rather than water from the stream. In other respects follow the water temperature protocol as described.

Students practice the protocol. Individually or in teams, students practice the same steps that you demonstrated. Watch them closely and help them perfect their technique. Have students share among themselves any insights they've gained on how to do the protocol correctly.

Example - Have your students work in teams in the classroom to measure tap water temperature, each team using its own thermometer.

Record and discuss the practice data. As your students practice the protocol, have them record their measurements. Review these measurements with your students and discuss the range of results. If there are any abnormal measurements, discuss why these might have occurred. This introduces the concept of data quality, which is essential for the entire GLOBE program. Help the students improve their technique to resolve any problems. Continue taking measurements until they are all sufficiently consistent.

Example - One student consistently had warmer temperature readings until his classmates noticed that he held his hands around the glass of water, which artificially warmed the water.

Phase IV - Doing the Real Thing

Get all your materials ready and go to the study site. Have your students gather the instruments, the data recording sheet, pens or pencils, and any other materials that are needed to do the measurement. Go to the study site with your class, taking the materials along.

Example - Take a bucket, rope, thermometer, pencils and data sheets on a clipboard to Meadowbrook stream.

Demonstrate the full protocol at the study site. Your students have practiced most of the protocol in the classroom, but there may be new elements for them to learn, now that they are at the actual study site. Demonstrate the full protocol and make sure your students understand it.

Example - The new element for water temperature is the use of a bucket to collect the real water sample from Meadowbrook Stream, rather than using classroom tap water.

Students do the real protocol at the study or sample site. Have your students do the protocol step by step. Watch closely to make sure that they are doing everything correctly. You may want to let them make mistakes and then correct them and learn from their mistakes as part of this process.

Example - For a fast-moving stream, students need to throw the bucket into a well-mixed area of the stream. If they do not hold onto the rope, which is tied to the bucket, the bucket will either sink or flow downstream.

Check the data for reasonableness. After your students have completed the protocol and recorded the measurement on the data work sheet, have them think about the data. Is it a reasonable value? If not, try to figure out why not and correct the problem.

Example - On route to the study site, the thermometer may have broken, causing it to show the same temperature, all the time.

Submit the data. Return to the classroom or laboratory. Use the GLOBE Web pages to submit the data to the GLOBE Student Data Server. After entering the data on screen, but before actually submitting the data entry sheet, have your students check the values to make sure that their entries are correct. If you are at a school outside the U.S. and do not have access to the World Wide Web, check with your Country Coordinator about the data entry process that you should use.

Example - The temperature of Meadowbrook Stream on this day was 16° C. The location of the Meadowbrook stream study site and the measured temperature value of 16° C were entered and sent to the GLOBE database.

Phase V - Submitting and Using the Data on an Ongoing Basis

Do the protocol on the prescribed schedule throughout the year. Many of the protocols specify daily or weekly measurements. Refer to the guidelines for details. Your students should repeat the procedure on this schedule. You can either have the whole class participate or assign the task to individuals or a team of students. They should conduct the measurements, record their observations, review the data for accuracy, and submit the data to the GLOBE database. Each GLOBE school should maintain a local record of its students observations and save this record indefinitely. This is a part of good science practice wherever measurements are made.

Example - Water temperature should be measured once every month.

Data quality requires ongoing attention. The work of the scientists requires that GLOBE student data be of consistently high quality. Emphasize this point to your students and make sure that they carefully and consistently follow the protocols and that they always review their data for reasonableness. To help them improve their accuracy, you can do some learning exercises, such as trying to create wrong measurements (which you do not submit!) and graphing their local data over time to look for spikes indicating unusual values which often indicate bad measurements. There are specific learning activities in several investigations that are built on exercises of this type.

Example - Have students warm the water in the bucket with their hands, by blowing on it, and by leaving it in the sun for an extended period of time. Have them take temperature measurements every minute to monitor this artificial warming.

Students use the data for their own investigations. The measurements that your students do are extremely valuable, not only for the scientists but also for your students to explore. They can learn important science concepts and develop skills of scientific investigation by examining their local data and data from other schools all over the world. The GLOBE software has very powerful tools to support accessing student data, analyzing it, and exploring visualizations of patterns in the data worldwide. Your students' investigations, in turn, help your students better understand the protocols and appreciate the essential role that they have in the GLOBE science and education program. There are GLOBE learning activities designed to provide a framework for getting started with investigations by exploring and comparing data sets provided by schools worldwide.

Example - Your students can compare their local water temperature measurements with measurements from other schools in the same geographical region to learn about regional water temperature variations. They share their findings with students in other GLOBE schools and with GLOBE scientists.

How To Make GLOBE a Meaningful Scientific Project for Your Students

GLOBE can be a terrific scientific experience for your students. Through participating in a genuine global research project, in which the investigations have been designed by scientists, they experience firsthand the excitement, the rigor, and the challenges of real science. Your students are direct participants in real scientific research. They contribute data which are used by scientists to generate new knowledge about the Earth. Through the GLOBE learning activities students can conduct their own investigations of the environment. Here are some things you can do to help make GLOBE an exciting scientific experience for your students.

Stress That the Scientists Need Your Data

The GLOBE program is unique in the degree to which scientists will actually use the data collected by students. It is, in this sense, a bold experiment. Through the design of rigorous protocols and through thorough training of teachers, the GLOBE program has tried to increase the probability that the data collected are of high quality. In the end, however, GLOBE is entirely dependent on how well you and your students carry out your data collection and follow the protocols.

We believe that students will be motivated to put out the effort to obtain quality data only if they understand the science behind the protocols, understand the importance of their data to the scientific enterprise, and support the overall research purpose. Quality data depends on quality education. The learning activities in the investigations help students obtain this quality education. Through these activities the students will learn science and mathematics concepts and skills as well as science processes. Also, they will gain understanding of the importance of precision, accuracy, and consistency in doing the protocols and of how scientists do research. Students will learn how they can pursue their own scientific investigations.

Personalize the GLOBE Scientists for Your Students

In each module we have provided photographs of the scientists who designed the investigation, an interview with the scientists, and a personal letter from them to your students. Use these materials to introduce the scientists to your students on a personal level.

On the GLOBE Web site you will find a section called the Scientists Corner. Have your students visit this page to view on-line photographs of the scientists and to read reports from the scientists about their work with the GLOBE program and other interesting topics.

Encourage Students to Contact Other GLOBE Schools

One of the exciting things about the GLOBE program is the opportunity it provides your students to meet, communicate with, and work with students in other schools around the world. Using GLOBEMail, your students can exchange messages with any school participating in GLOBE. For example, your students might ask students elsewhere to join them in carrying out a cooperative data-collection activity, enter into a collaborative research project, or exchange information about their lives and communities.

Through the GLOBE Student Data Server, your students can retrieve the data that any school has submitted. In the *GLOBE Stars* section of the GLOBE Web site, they can view schools that have been selected for special mention because of their participation in GLOBE. As the GLOBE Stars change frequently, your students should check this section regularly.

Use GLOBE Telecommunications

Your electronic link with GLOBE is through the World Wide Web. Through the GLOBE Web site, you can: obtain bulletins and updates; read background information about the program, the scientists, and other schools; submit your data; examine and retrieve data from other schools; look at graphic representations of both the GLOBE student data and other global data and model predictions; and exchange GLOBEMail with other GLOBE schools. You will have received instructions on using the GLOBE Web site at your GLOBE Teacher Training Workshop.

Use GLOBE Science Notebooks

Encourage your students to keep a GLOBE Science Notebook, a scientific journal or notebook where each student can record all kinds of thoughts and observations. Such a notebook can be an unique mix of private and public work, a place for students to record reflections, ideas, hypotheses, questions, observations, and sketches, as well as transcribe lab results and data as they progress through their GLOBE work. We hope each student will keep a GLOBE Science Notebook.

- Set aside regular times for students to work in their GLOBE Science Notebooks during the week. If you review the notebooks periodically, you will be able to follow students' developing understanding and assess their learning.
- You might want your students to trade their GLOBE Science Notebooks with one another to learn about how other students take notes; they can attach comments to each other's work in a session on Peer Review.
- As they write in their GLOBE Science Notebooks , encourage students to be broad and daring in their reflections on their work, and persistent and careful in their transcription and use of data.
- Drawing and recording in their GLOBE Science Notebooks helps students to focus and magnify their powers of observation. No two notebooks look alike because each person needs to record information in a way that makes sense to him or her. Some people, for example, rely more on pictures than on text, whereas others prefer to capture most of their observations in numbers. Each student should experiment to find out what works best for him or her.

Each entry in the GLOBE Science Notebook should include:

- Date
- Location
- Time
- If a field entry, environmental variables such as weather
- Questions, hypotheses, methods, observations, analyses, conclusions, ideas

The information gathered in the GLOBE Science Notebook should be used to help students prepare papers and presentations on their investigations and projects. These can be presented in class, at school assemblies, and community events, and submitted to journals for publication.

How To Help Your Students Design Their Own Investigations

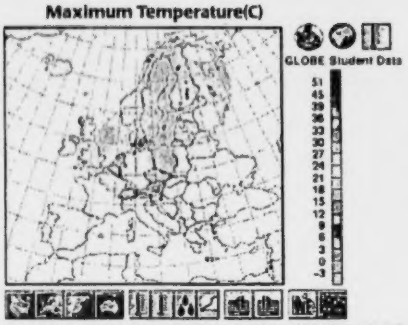
Encouraging students to conduct science investigations is at the heart of GLOBE's approach to education. Your students can use data from their own GLOBE Study Site, as well as data from other schools, to ask questions, seek answers by looking at real data, pursue their own interests, establish partnerships with other schools throughout the world, and explore the interconnections among the various phenomena which comprise the Earth system. The investigation *Seasons: Putting It All Together* provides a series of learning activities using local and global data to answer questions. Students may design their own investigations as well. This section contains some thoughts to keep in mind as you proceed.

Remember, although investigations can be a lot of work, joy usually accompanies satisfying one's own curiosity and gaining new understanding.

1. **The nature of your investigations will depend on local factors.** While GLOBE offers an incredibly rich resource of worldwide data and potential areas of investigation, the exact nature of student investigations will vary from school to school. It will depend on the characteristics of your own GLOBE Study Site, the GLOBE data you use, the interests of your students, your own interests and expertise, the capabilities and expertise that is made available to your students from their community, the technology available to you, the age and experience level of your students, and the amount of time that you have available.
2. **Investigations should be based on student questions.** Investigations begin with questions. Even if you focus students on a specific area, the investigations themselves must begin with questions that the students are sincerely asking. If they really want to find out the answer, then the rest of the investigation falls into place with logic, meaning, and purpose for the students. This is crucial to their enjoyment of an investigation.
3. **Students should take direct observations.** Students' investigations should be grounded in their observations of the phenomena they are studying. This is what makes the investigation real for them - understanding how data correspond to actual phenomena they can observe.
4. **Students should use data from the GLOBE Student Data Server.** This database of student observations is a unique and valuable resource to support student research and learning. In one way or another, all investigations can take advantage of this increasingly rich database.
5. **Students should build on what they know.** Your students will collect data for the *Atmosphere, Hydrology, Soil,* and *Land Cover/Biology Investigations*. They should also do a variety of related learning activities to strengthen their understanding of the measurement protocols and resulting data. The investigations should build on this knowledge base.
6. **Students should tap other sources of information.** Using other sources of information does not mean that your students should rely on encyclopedias or other reference books to find answers. Rather, your students should pursue other sources of data and representations of these data such as images, graphs, tables of data, and other visualizations available through GLOBE. Historical data from local environmental agencies, Landsat TM and other satellite data, regional topographical maps, or Internet searches on the World Wide Web complement and extend the data resources directly provided by GLOBE. As much as possible, students should rely on and try to interpret primary sources of data, rather than standard textbooks. Of

course, books certainly provide explanations for phenomena that help students better structure their investigations.

7. **Students should collaborate with other GLOBE students throughout the world.** GLOBE epitomizes this in the scientists' reliance on data from thousands of students worldwide. Most Earth scientists work in teams because of the extensive nature of environmental research. So too, student investigations usually are strengthened or enabled by collaboration among several students who divide the responsibilities and share their thoughts. Because many GLOBE schools have telecommunications, student investigations can involve collaborations with other schools all over the world.
8. **Your students can do investigations at any point in the year.** All of the GLOBE investigations emphasize hands-on, inquiry-based approaches. The best time for an investigation is when the students are truly engaged and curious about something they see at their study site, in the GLOBE data, or in the news.
9. **Investigations can be short or long.** Some investigations can be done in a single day; others will take a lifetime. Help your students to set achievable objectives so that they can see results from their work before they loose interest.
10. **Generally, there may be no single right answer.** Students tend to assume that answers are either right or wrong, but for many questions, there is no single right answer. For example, if the question is "When is the rainiest time of the year?" your students will find different answers for different parts of the world, and they will find that rainy seasons do not always begin and end on specific days.
11. **Most investigations are interactive and messy.** The straight-line concept of the scientific method is not generally how science takes place. In many cases, one does not simply state a hypothesis, collect data, and prove or disprove the hypothesis. The process involves asking many questions, exploring the data, making guesses, doing more observations, rethinking the questions, checking other sources, discussing and arguing with colleagues, and questioning underlying assumptions. This is the reality of science, and it is an approach we hope your students will adopt.



GLOBE Visualization, showing a map with student data.

12. **One investigation will lead to another.** If the topic is truly engaging for your students, one investigation likely will lead to another. For example, your students may determine the coldest day of the current year, but that in turn may lead to the question of why it was so early or late in the year, or whether other places in the world similarly had an early or late coldest day.
13. **Explore local issues.** GLOBE observations provide several perspectives on your local environment. Addressing a local issue may require your students to make other observations. You and they can seek out local organizations as collaborators. When students realize that they can contribute to their community or interact with scientists directly, it is often a boost to morale and confidence. Many areas of scientific investigation are pursued to satisfy individual curiosity, but environmental investigations almost always are done to meet a community or societal need for understanding as well.

GLOBE Outreach

The GLOBE program is a partnership among the U.S. Federal Government, other countries, U.S. state and local governments, schools, and the private sector. Outreach activities can help promote local interest in and support for your school's GLOBE Program activities. This section includes outreach ideas, tips on writing a press release and working with the media and sample press releases and articles. These materials are intended to be a starting point. To achieve the best results, adapt them to your school and community. Also, encourage your students to develop their own outreach activities.

GLOBE School Outreach Ideas

- Hold a GLOBE Open House and invite local citizens (e.g. parents, school superintendents, city officials, other government officials, and environmental clubs) and the media to join students in making scientific measurements and observations. Allow the students to demonstrate how they report the data via the Internet. Discuss the online, graphic visualizations of the GLOBE student data and let the students explain how their work contributed to the image and to their understanding of the Earth's environment. See *Working with the Media* in this section.
- Schedule a school assembly or PTA meeting to recognize the GLOBE teacher and students. Students can make presentations of their data and talk about what they have learned.
- Help the students organize a GLOBE "Speakers Bureau" and seek opportunities to address local business and civic organizations. Students can demonstrate what they are learning about both the environment and technology. This is important to help meet the GLOBE goal of improving environmental awareness.
- Invite professionals in the environmental, science, and technology fields to meet with GLOBE students. This will help the students to see the value of their work beyond the classroom while also helping these professionals learn more about GLOBE.
- Have GLOBE students submit articles and photographs to the local newspaper. The local newspaper may want to feature GLOBE student observations regularly on their education or "kids" pages. Local television stations may be interested in including GLOBE data in their nightly weather reports or science and education features.
- Show the GLOBE video to small groups to help provide the overview of the program or let your students make their own GLOBE video or slide show.

Working With The Media

If you are contacted by the media or decide to seek media coverage of your GLOBE Program activities, the following hints may be helpful. Your local government or school public affairs office also might offer guidance.

Developing Your Message and Knowing Your Subject Matter

Take some time to decide exactly what it is you want the media to say about your GLOBE Program activities. Are you looking for coverage of a particular event, such as a GLOBE Open House, or are you hoping for a general feature story on the school activities? See *Writing a GLOBE News Release* and be sure to check the updated GLOBE Program information at http://www.globe.gov so that you can provide accurate answers to questions such as, "How many schools and how many countries are involved?" Also, if you are uncertain about any aspect of the program, send an email message to: info@globe.gov and you will receive a prompt response.

Invitations

You may choose to invite just one local paper or television station to visit your school at a particular time, or you can hold an event to which you invite all local media. The single invitation is easier to conduct and reporters and editors are more likely to be attracted to an "Exclusive." Multiple invitations require more preparation and work in carrying out, but can produce wider coverage of your GLOBE Program activities. Including dignitaries with the students may broaden media interest, yet students are "the story." The choice of a single or multiple invitation well may depend on how much interest your news media has in GLOBE when you approach them.

Establishing Key Media Contacts

If you, your principal, or a GLOBE parent knows someone in a news organization, contact that individual first. If you don't have an inside contact, call the switchboard and ask for the name of reporters who cover environment, science, or education issues. Spend a few minutes on the phone explaining GLOBE and indicate that you will be sending additional materials or, if you are planning a special event, a press release. Captivate their interest so that they will want to accept an invitation to visit your students. If they seem disinterested or rushed, try again after a few weeks or, better yet, ask if there is someone else in the office they would suggest to contact.

Timing Your Contacts

Reporters need at least one week advance notice for special events, preferably two weeks. Follow up your press release with a phone call. Don't be afraid to call the day before to confirm attendance.

Planning Your Event

To ensure good turn-out, time your event to begin no earlier than 10:00 a.m. Make sure there is plenty of open space for cameras and microphones. Check with the news organizations ahead of time to see if they need access to electrical outlets or have other special needs. When a reporter arrives for an event, make sure someone is responsible for greeting the reporter and introducing the reporter to the principal, the GLOBE teacher, students, and any VIPs in attendance. Prepare a press package for each reporter with another copy of the press release, print-outs of GLOBE visualizations, a copy of the event agenda, and any other materials which help describe your GLOBE Program.

Follow-up

After a media visit to your GLOBE school, call the news organization to make sure they have all the information they need. If there are significant inaccuracies in the story, you should politely notify the news organization of the errors.

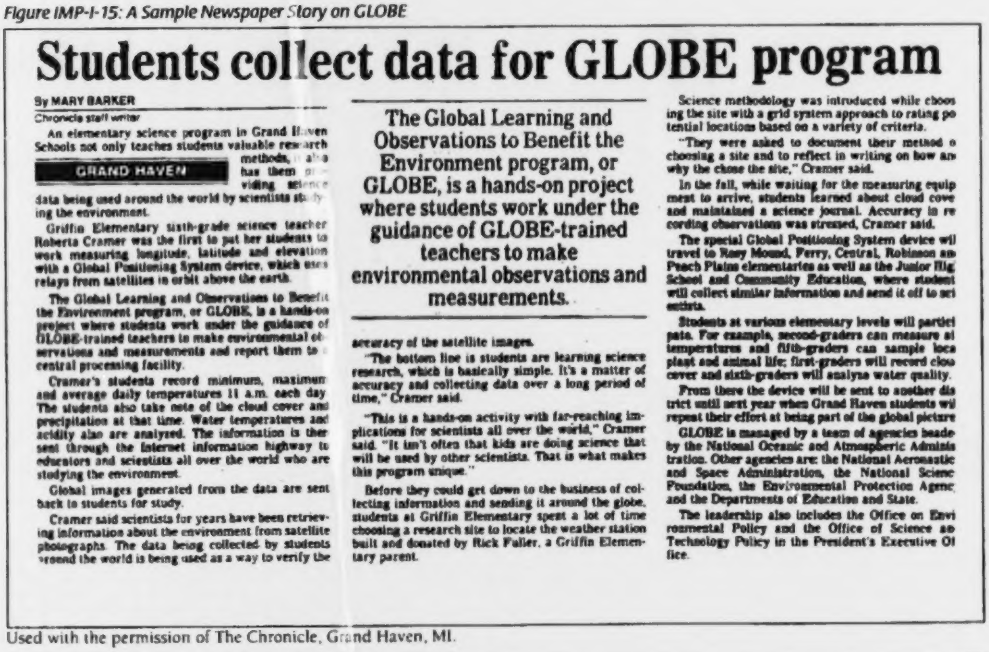


Figure IMP-I-15: A Sample Newspaper Story on GLOBE

Students collect data for GLOBE program

By MARY BARKER

Chronicle staff writer

An elementary science program in Grand Haven Schools not only teaches students valuable research methods, it also has them providing science data being used around the world by scientists studying the environment.

GRAND HAVEN

Griffin Elementary sixth-grade science teacher Roberta Cramer was the first to put her students to work measuring longitude, latitude and elevation with a Global Positioning System device, which uses relays from satellites in orbit above the earth.

The Global Learning and Observations to Benefit the Environment program, or GLOBE, is a hands-on project where students work under the guidance of GLOBE-trained teachers to make environmental observations and measurements and report them to a central processing facility.

Cramer's students record minimum, maximum and average daily temperatures 11 a.m. each day. The students also take note of the cloud cover and precipitation at that time. Water temperatures and acidity also are analyzed. The information is then sent through the Internet information highway to educators and scientists all over the world who are studying the environment.

Global images generated from the data are sent back to students for study.

Cramer said scientists for years have been retrieving information about the environment from satellite photographs. The data being collected by students around the world is being used as a way to verify the accuracy of the satellite images.

"The bottom line is students are learning science research, which is basically simple. It's a matter of accuracy and collecting data over a long period of time," Cramer said.

"This is a hands-on activity with far-reaching implications for scientists all over the world," Cramer said. "It isn't often that kids are doing science that will be used by other scientists. That is what makes this program unique."

Before they could get down to the business of collecting information and sending it around the globe, students at Griffin Elementary spent a lot of time choosing a research site to locate the weather station built and donated by Rick Fuller, a Griffin Elementary parent.

The Global Learning and Observations to Benefit the Environment program, or GLOBE, is a hands-on project where students work under the guidance of GLOBE-trained teachers to make environmental observations and measurements.

Science methodology was introduced while choosing the site with a grid system approach to rating potential locations based on a variety of criteria.

"They were asked to document their method o choosing a site and to reflect in writing on how an why the chose the site," Cramer said.

In the fall, while waiting for the measuring equipment to arrive, students learned about cloud cove and maintained a science journal. Accuracy in recording observations was stressed, Cramer said.

The special Global Positioning System device wil travel to Rosy Mound, Perry, Central, Robinson an Peach Plains elementaries as well as the Junior Hig School and Community Education, where student will collect similar information and send it off to scientists.

Students at various elementary levels will participate. For example, second-graders can measure ai temperatures and fifth-graders can sample loca plant and animal life; first-graders will record clou cover and sixth-graders will analyze water quality.

From there the device will be sent to another district until next year when Grand Haven students wil repeat their effort at being part of the global picture

GLOBE is managed by a team of agencies heade by the National Oceanic and Atmospheric Administration. Other agencies are: the National Aeronautic and Space Administration, the National Scienc Foundation, the Environmental Protection Agenc and the Departments of Education and State.

The leadership also includes the Office on Envi ronmental Policy and the Office of Science an Technology Policy in the President's Executive Of fice.

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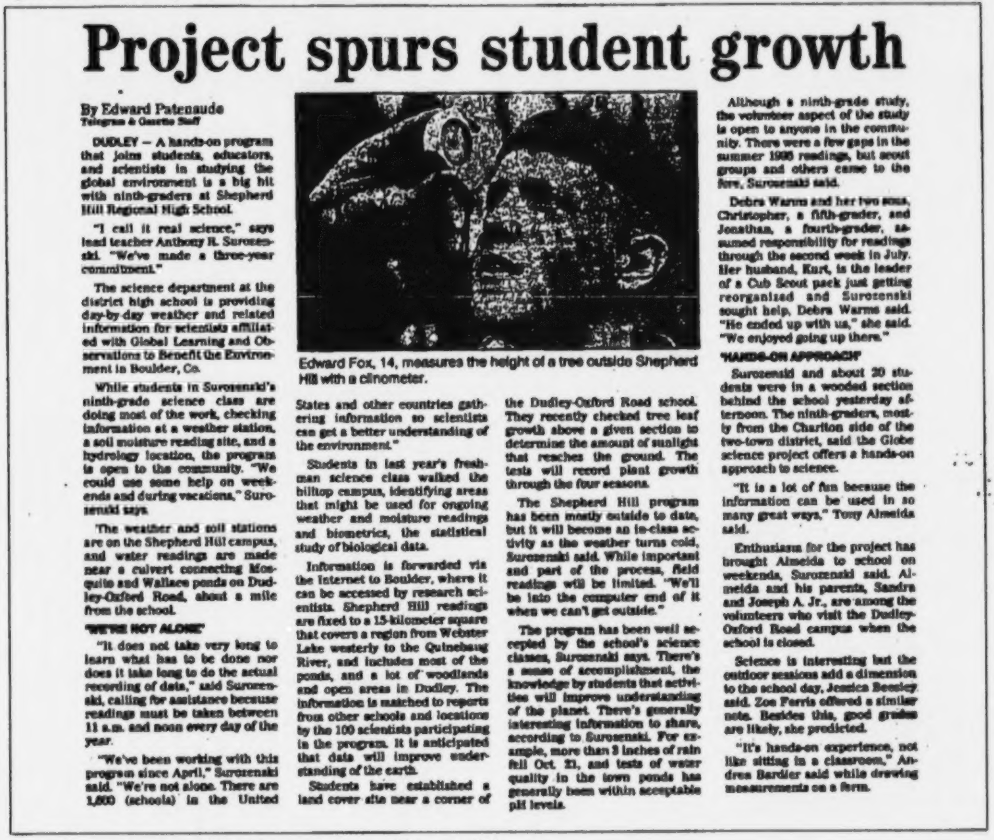
Figure IMP-I-16: A Sample Newspaper Story on GLOBE



Project spurs student growth

By Edward Patenaude
Telegram & Gazette Staff

DUDLEY – A hands-on program that joins students, educators, and scientists in studying the global environment is a big hit with ninth-graders at Shepherd Hill Regional High School.

"I call it real science," says lead teacher Anthony R. Surozenski. "We've made a three-year commitment."

The science department at the district high school is providing day-by-day weather and related information for scientists affiliated with Global Learning and Observations to Benefit the Environment in Boulder, Co.

While students in Surozenski's ninth-grade science class are doing most of the work, checking information at a weather station, a soil moisture reading site, and a hydrology location, the program is open to the community. "We could use some help on weekends and during vacations," Surozenski says.

The weather and soil stations are on the Shepherd Hill campus, and water readings are made near a culvert connecting Mosquito and Wallace ponds on Dudley-Oxford Road, about a mile from the school.

'WE'RE NOT ALONE'

"It does not take very long to learn what has to be done nor does it take long to do the actual recording of data," said Surozenski, calling for assistance because readings must be taken between 11 a.m. and noon every day of the year.

"We've been working with this program since April," Surozenski said. "We're not alone. There are 1,800 (schools) in the United States and other countries gathering information so scientists can get a better understanding of the environment."

Edward Fox, 14, measures the height of a tree outside Shepherd Hill with a clinometer.

Students in last year's freshman science class walked the hilltop campus, identifying areas that might be used for ongoing weather and moisture readings and biometrics, the statistical study of biological data.

Information is forwarded via the Internet to Boulder, where it can be accessed by research scientists. Shepherd Hill readings are fixed to a 15-kilometer square that covers a region from Webster Lake westerly to the Quinebaug River, and includes most of the ponds, and a lot of woodlands and open areas in Dudley. The information is matched to reports from other schools and locations by the 100 scientists participating in the program. It is anticipated that data will improve understanding of the earth.

Students have established a land cover site near a corner of the Dudley-Oxford Road school. They recently checked tree leaf growth above a given section to determine the amount of sunlight that reaches the ground. The tests will record plant growth through the four seasons.

The Shepherd Hill program has been mostly outside to date, but it will become an in-class activity as the weather turns cold, Surozenski said. While important and part of the process, field readings will be limited. "We'll be into the computer end of it when we can't get outside."

The program has been well accepted by the school's science classes, Surozenski says. There's a sense of accomplishment, the knowledge by students that activities will improve understanding of the planet. There's generally interesting information to share, according to Surozenski. For example, more than 3 inches of rain fell Oct. 21, and tests of water quality in the town ponds has generally been within acceptable pH levels.

Although a ninth-grade study, the volunteer aspect of the study is open to anyone in the community. There were a few gaps in the summer 1996 readings, but scout groups and others came to the fore, Surozenski said.

Debra Warms and her two sons, Christopher, a fifth-grader, and Jonathan, a fourth-grader, assumed responsibility for readings through the second week in July. Her husband, Kurt, is the leader of a Cub Scout pack just getting reorganized and Surozenski sought help, Debra Warms said. "He ended up with us," she said. "We enjoyed going up there."

'HANDS-ON APPROACH'

Surozenski and about 20 students were in a wooded section behind the school yesterday afternoon. The ninth-graders, mostly from the Charlton side of the two-town district, said the Globe science project offers a hands-on approach to science.

"It is a lot of fun because the information can be used in so many great ways," Tony Almeida said.

Enthusiasm for the project has brought Almeida to school on weekends, Surozenski said. Almeida and his parents, Sandra and Joseph A. Jr., are among the volunteers who visit the Dudley-Oxford Road campus when the school is closed.

Science is interesting but the outdoor sessions add a dimension to the school day, Jessica Beesley said. Zoe Ferris offered a similar note. Besides this, good grades are likely, she predicted.

"It's hands-on experience, not like sitting in a classroom," Andrea Bardier said while drawing measurements on a form.

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Writing a GLOBE News Release

Five points are important to a good news release: **Who**, **What**, **When**, **Where** and **Why**. If possible, a sixth, **How**, should be included. It is important to get all these points in the first sentence or two. Use short words and write short sentences and short paragraphs. Two sentences make a good paragraph in a news release. Almost every news release can be written on one or two typewritten pages.

Remember

- Always give exact date, time, and location of your event, including the location for media parking and specific entrance information.
- Provide at least a two- or three-sentence description of the overall GLOBE Program, including information on the number of schools and countries involved.
  (Check the GLOBE Home Page at http://www.globe.gov for up-to-date information.)
- Check every point of your release for accuracy. Never guess on dates, times, places, or spelling of names.
- Put school contact person and phone number at the top corner of the release, and print the release on school letterhead.

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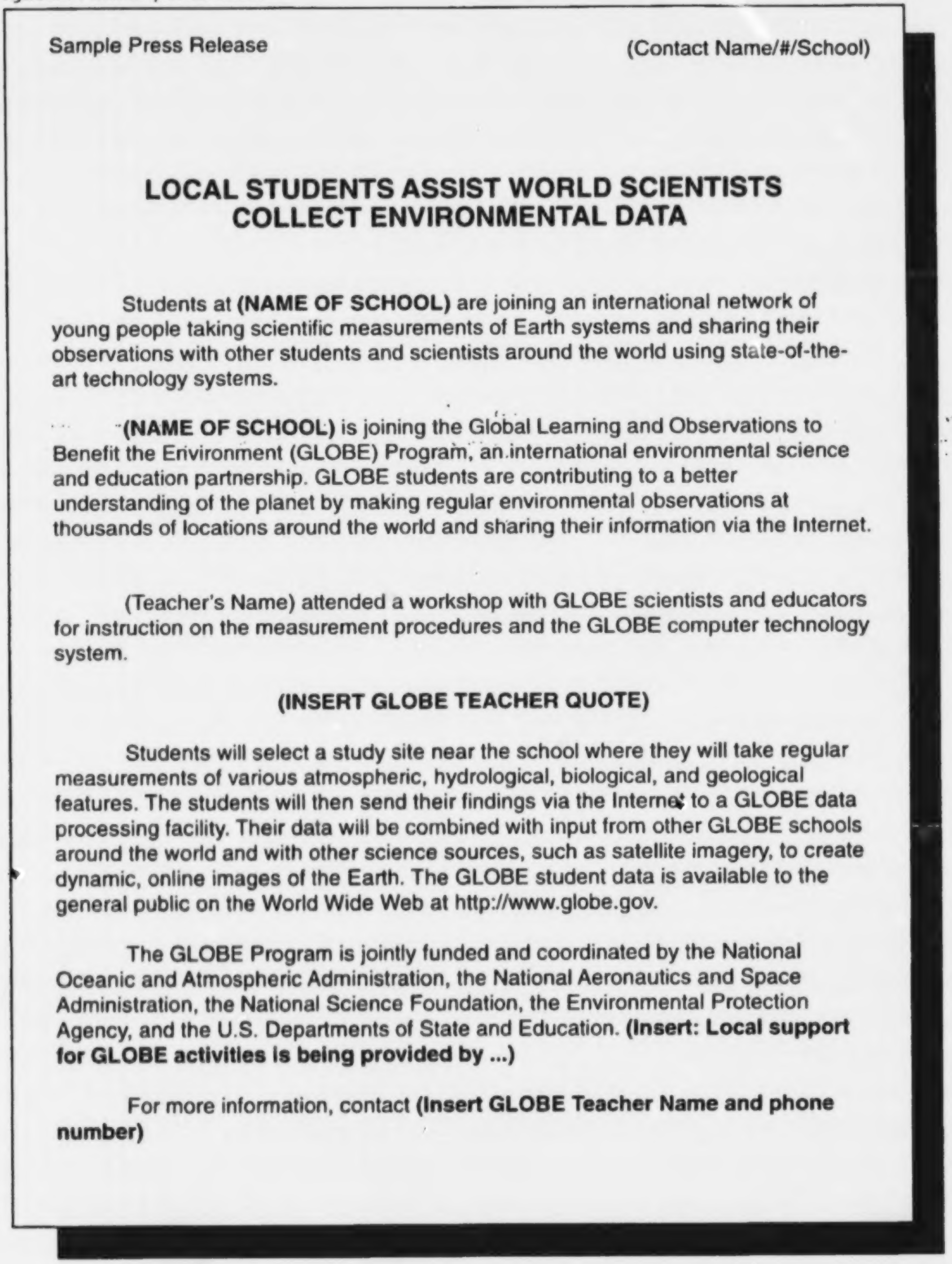
Figure IMP-I-17: A Sample Press Release



Sample Press Release (Contact Name/#/School)

LOCAL STUDENTS ASSIST WORLD SCIENTISTS COLLECT ENVIRONMENTAL DATA

Students at **(NAME OF SCHOOL)** are joining an international network of young people taking scientific measurements of Earth systems and sharing their observations with other students and scientists around the world using state-of-the-art technology systems.

(NAME OF SCHOOL) is joining the Global Learning and Observations to Benefit the Environment (GLOBE) Program, an international environmental science and education partnership. GLOBE students are contributing to a better understanding of the planet by making regular environmental observations at thousands of locations around the world and sharing their information via the Internet.

(Teacher's Name) attended a workshop with GLOBE scientists and educators for instruction on the measurement procedures and the GLOBE computer technology system.

(INSERT GLOBE TEACHER QUOTE)

Students will select a study site near the school where they will take regular measurements of various atmospheric, hydrological, biological, and geological features. The students will then send their findings via the Internet to a GLOBE data processing facility. Their data will be combined with input from other GLOBE schools around the world and with other science sources, such as satellite imagery, to create dynamic, online images of the Earth. The GLOBE student data is available to the general public on the World Wide Web at http://www.globe.gov.

The GLOBE Program is jointly funded and coordinated by the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, the National Science Foundation, the Environmental Protection Agency, and the U.S. Departments of State and Education. **(Insert: Local support for GLOBE activities is being provided by ...)**

For more information, contact **(Insert GLOBE Teacher Name and phone number)**

Learning Activities

Our Home Planet: The Global View

Students look at globes, maps, and photos of the Earth and consider Earth as a global system.

Our Special Place: The Local View

Students look at their local environment and compare their observations.

Our Home Planet: The Global View

Purpose

To introduce the GLOBE program to students and to provide them with an overview of GLOBE's most significant features

Overview

Students look at globes, maps and astronauts' photos of Earth, and consider the Earth system as a whole. They are then introduced to the key elements of the GLOBE program: the scientists, the study areas, and the international community of students.

Time

One class period

Key Concepts

Earth is a planet, functioning as a whole, with interconnected systems.

The scientific community works together to gain a deeper understanding of Earth's interconnections.

Students and teachers can be part of this community through their participation in the GLOBE Program.

Skills

Reflecting on the whole, in this case on the entire planet

Hypothesizing about the future of the planet

Brainstorming and *reflecting* upon the role of good data in scientific investigations

Level

All

Materials and Tools

The GLOBE whole Earth poster, photos of Earth from space taken by the astronauts, as well as many other images of the Earth you can find. You might include a globe, atlas, maps, and any other representations that will stimulate your students thinking about their planet.

GLOBE introductory video (optional)

Welcome letter to students (from Preface)

Preparation

None

Prerequisites

None

Background

Students today are fortunate to grow up with pictures of the whole Earth as seen from space-beautiful, blue, vulnerable, and rich in mysteries. We all profit from those brave early explorers of space who not only traveled into the unknown, but sent back words and pictures filled with their impressions of the Earth seen from afar. The very thinness of the atmosphere took the astronauts' breath away, while the Earth's color and complexity stood in sharp contrast with the gray and lifeless surface of the moon.

"From space I saw the Earth-indescribably beautiful with the scars of national boundaries gone."

Muhammed Ahmad Faris, Syria

"The first day or so we all pointed to our countries. The third or fourth day we were pointing to our continents. By the fifth day we were aware of only one Earth."

Sultan Bin Salman al-Saud,
the Kingdom of Saudi Arabia

"Now I know why I am here. Not for a closer look at the moon, but to look back at our home, the Earth."

Alfred Worden, USA

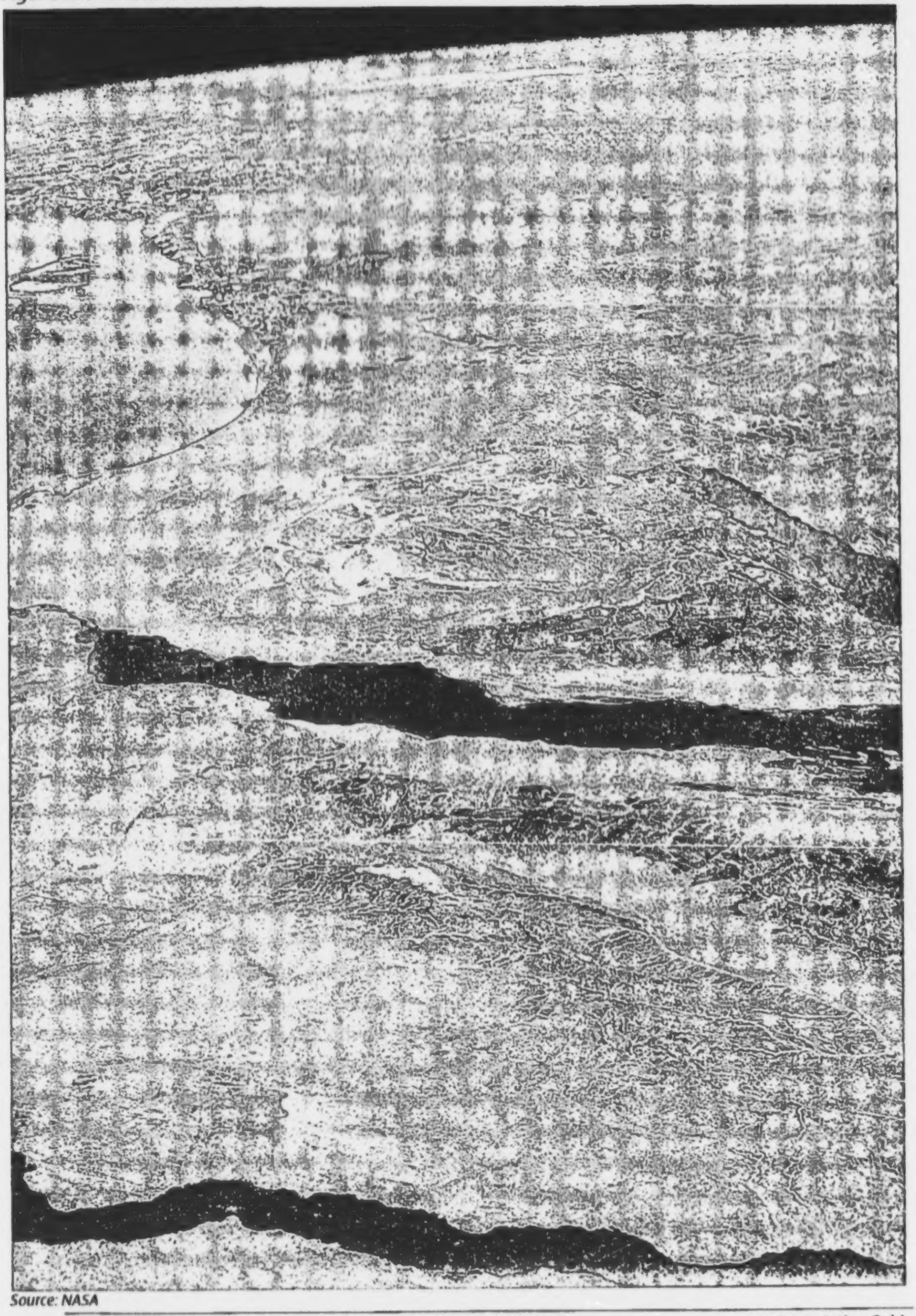
"I realized that mankind needs height primarily to better know our long-suffering Earth, to see what cannot be seen close-up. Not just to know her beauty, but also to ensure that we do not bring even the slightest harm to the natural world."

Pham Tuan, Vietnam

Figure IMP-L-1: An astronaut floats above the serene Earth

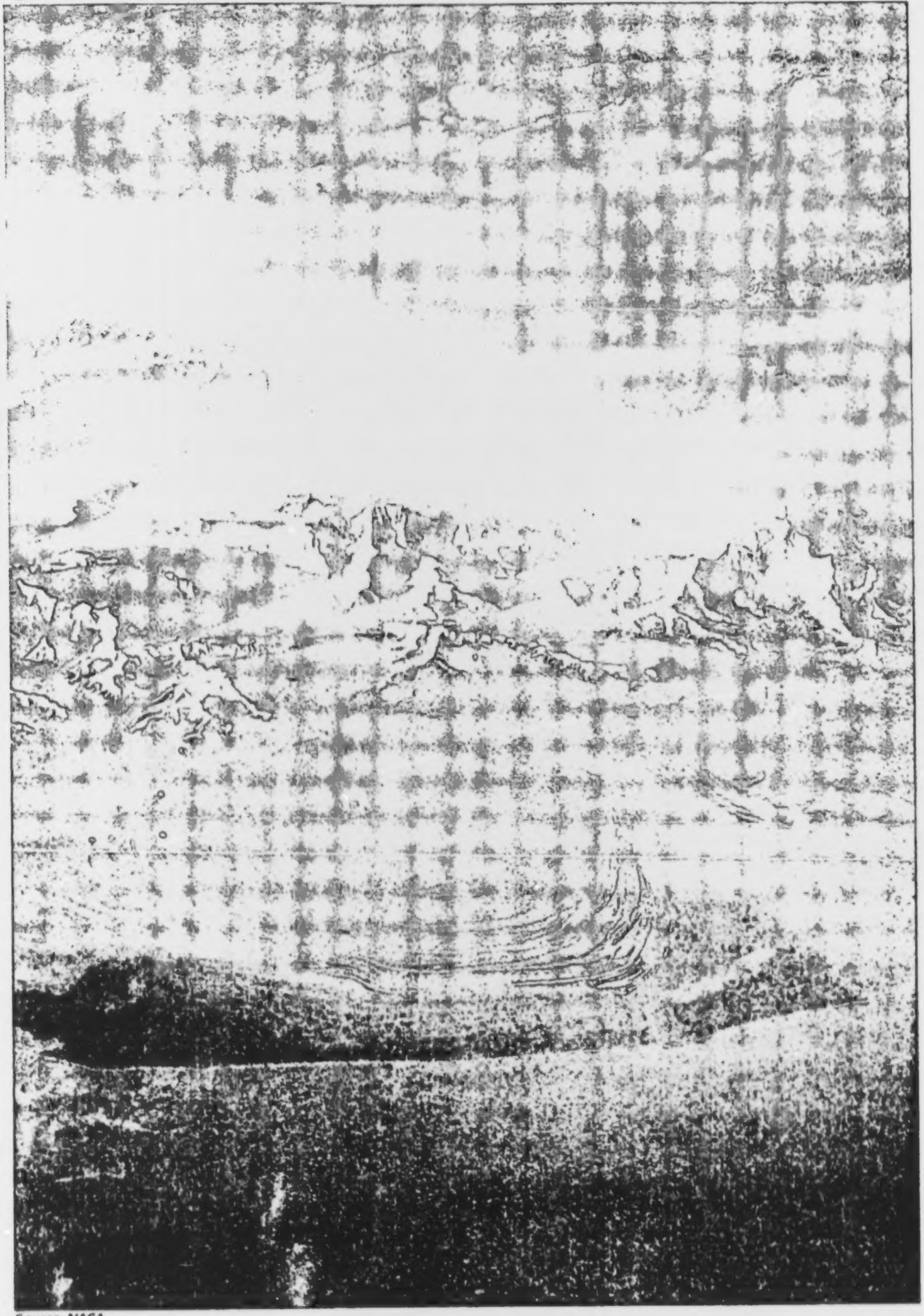
Source: NASA

Figure IMP-L-2: Middle East



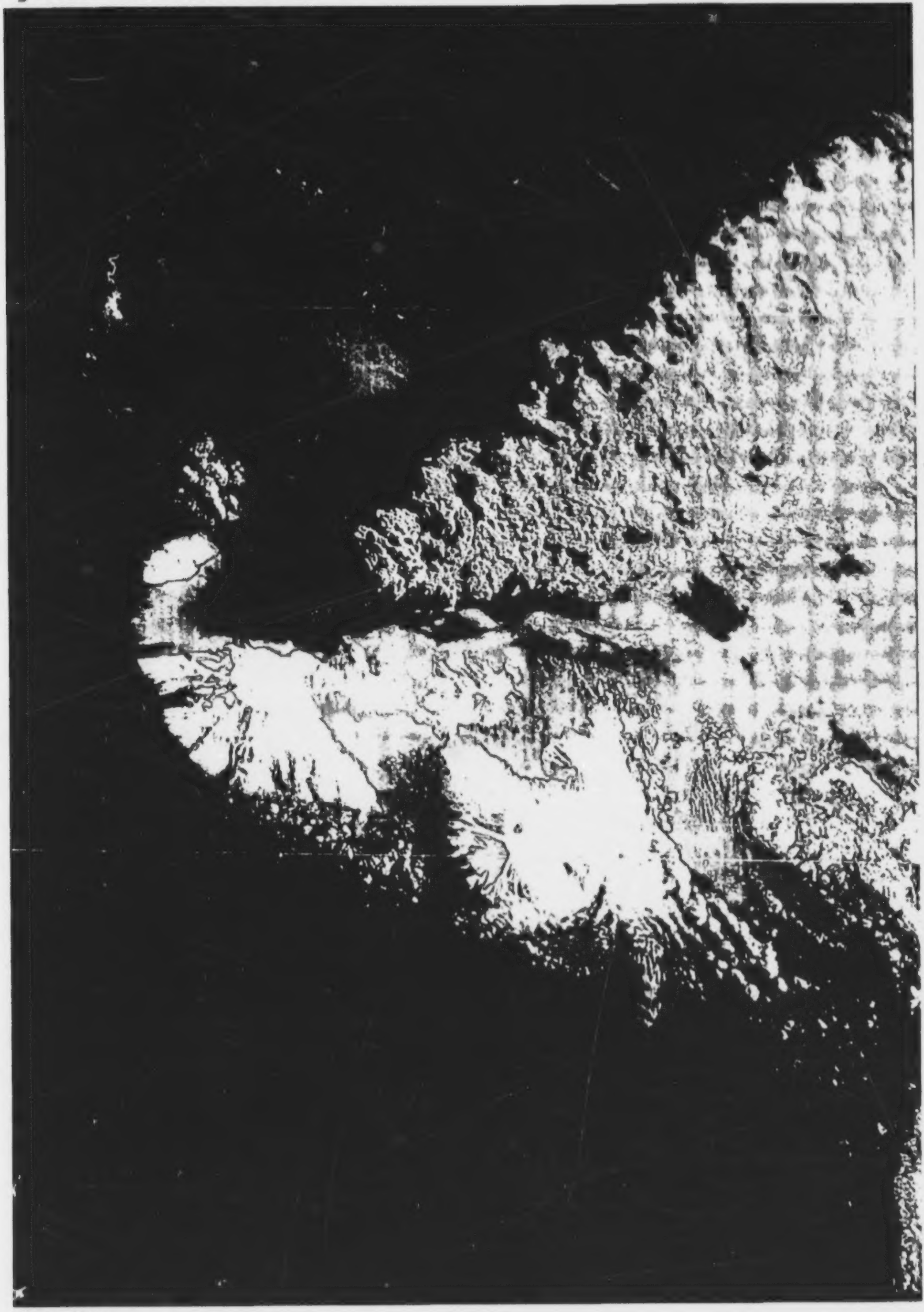
Source: NASA

Figure IMP-L-3: Malaspina Glacier



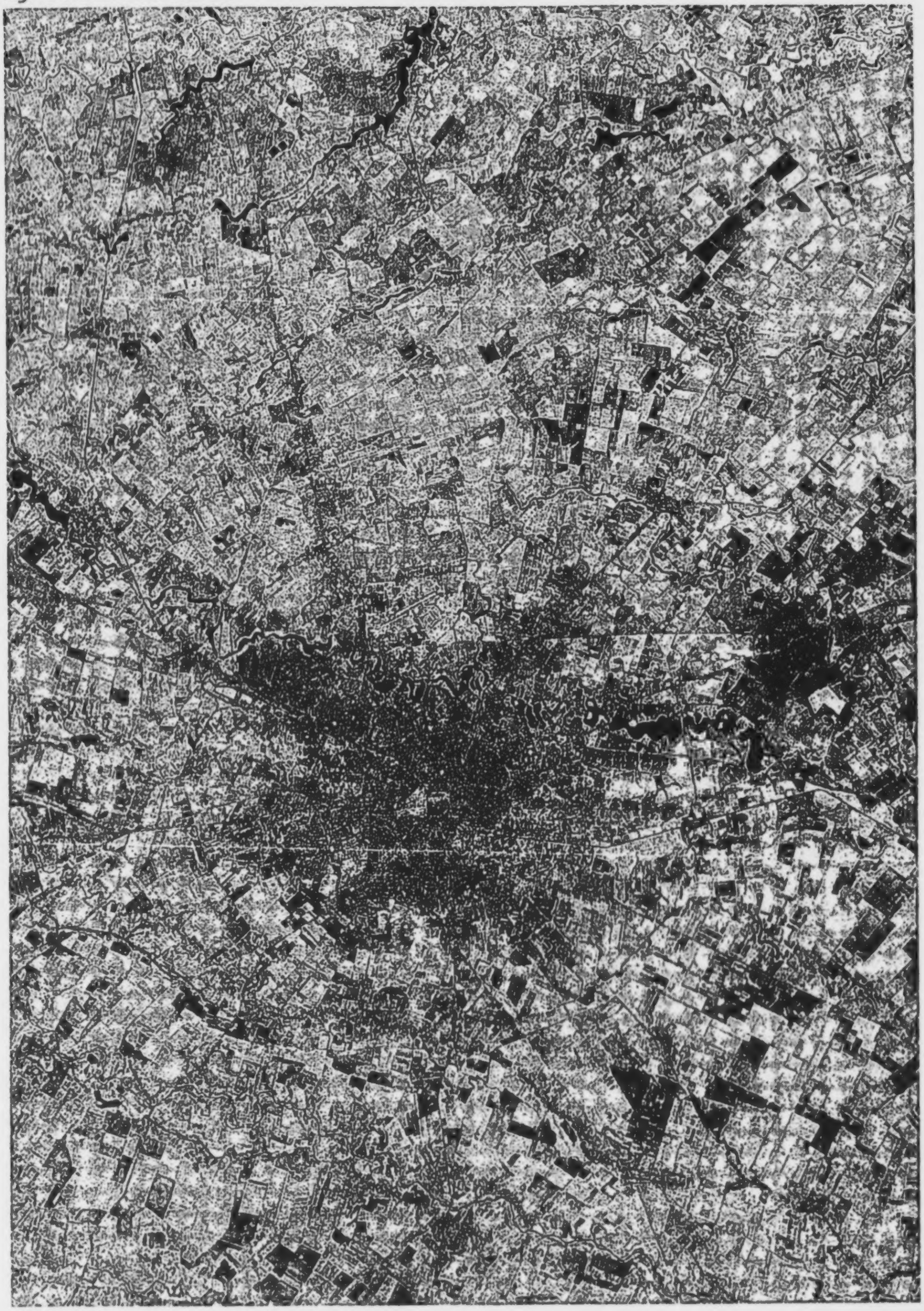
Source: NASA

Figure IMP-L-4: Kamchatka Volcano



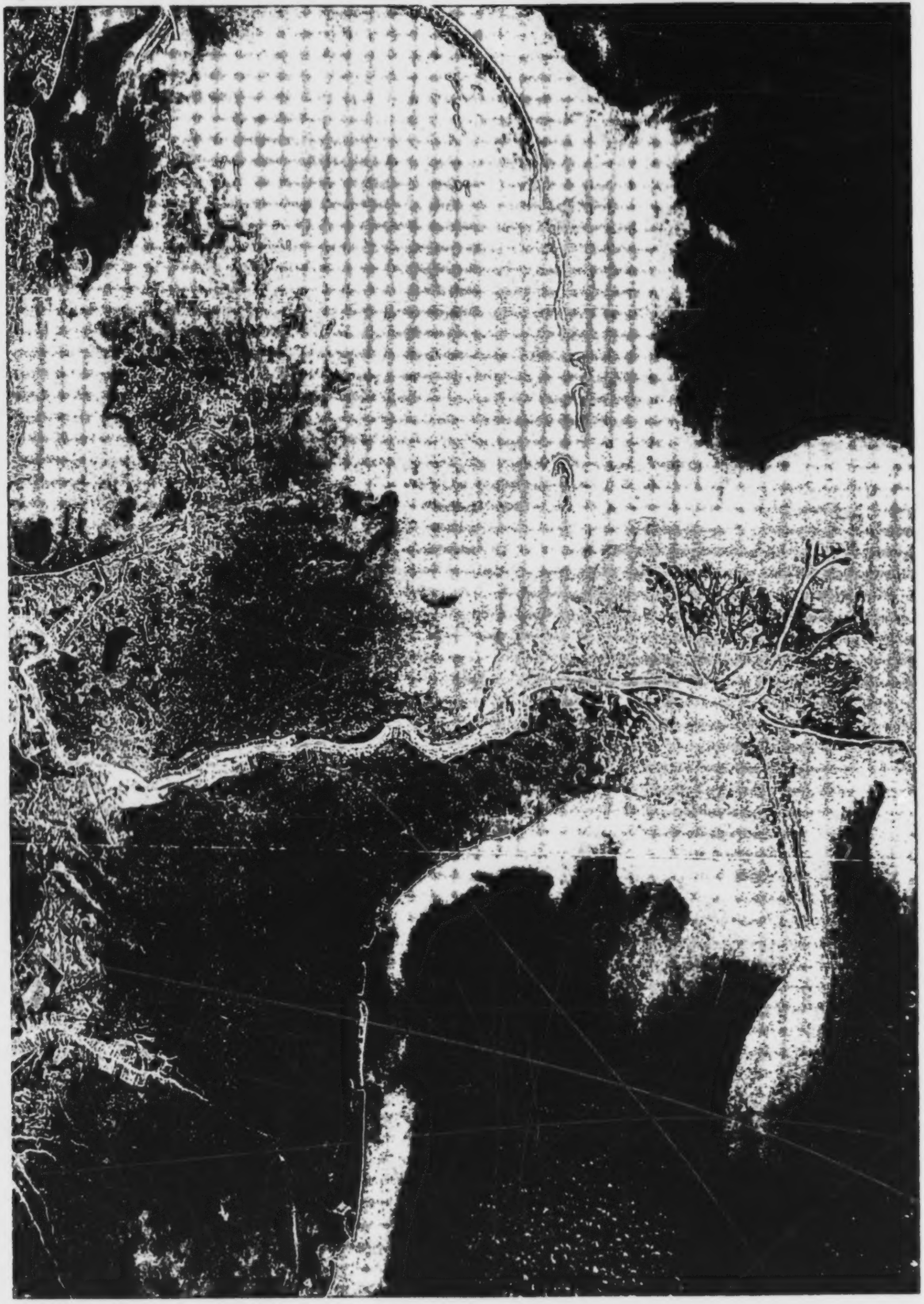
Source: NASA

Figure IMP-L-5: Bucharest



Source: NASA

Figure IMP-L-6: Mississippi River Delta



Source: NASA

"After an orange cloud-formed as a result of a dust storm over the Sahara and caught up by air currents-reached the Philippines and settled there with rain, I understood that we are all sailing in the same boat."

Vladimir Kovalyonok, USSR

(*Home Planet*, Conceived and edited by Kevin Kelley for the Association of Space Explorers. Moscow: Mir Publishers; New York: Addison Wesley, 1988)

In order to be better caretakers of the planet we need much more information about how our Earth system works. In GLOBE, our students gather critical data which help scientists understand the myriad interconnections among the land, water and air of Planet Earth.

What To Do and How To Do It

Step 1: Viewing Earth from Space

Place the Earth images in prominent positions about the classroom.

Give the students several minutes to observe the globe, posters and images of the whole Earth seen from space. Invite students to share their responses to the images of Earth. There are no right or wrong answers; any response is acceptable. Encourage your students to point out the Earth's outstanding physical features, to identify geographic areas with significantly different features, and in general, to think globally. Ask them to consider what might be evidence of life in the image. Could anything that happens in another part of the world affect what happens in your part of the world?

Step 2: Who do you know elsewhere in the world?

Select a globe or map to mark with small notes or push-pins. Ask your students who they know (friend or family) who lives outside of their own community. Ask your students to consider what they might learn from these people about their parts of the world. Is it warmer or colder in their area? Is there more rainfall? Heavier rainfall? Snow? Is the soil more sandy or better for growing crops? Is the rain and water more or less acidic than your own? Such a discussion will develop in students a sense of the value of each person's data. Point out that they will soon become experts in their own study sites, and will contribute that information to the world community.

Step 3: Brainstorm with your students

What could we learn about the Earth with data from students around the world?

We could learn more about:

- How is Earth able to support life?
  Beginning and intermediate students might mention the Earth's atmosphere, its water and other critical, but single, specific features.
  Advanced students might mention the way the planetary systems of water, soil and air work together, or the way organisms and the planet have evolved together.
- What challenges are faced by the Earth?
  Beginning and intermediate students might mention single examples of human impact or particular pollution problems such as oil spills or acid rain. They might simply say that we should study it.
  Advanced students might note the population explosion, and atmospheric changes. They might point out that, working together, we should study these changes, over time, in different parts of the world, sharing our findings.
- What might the world be like 50 and 100 years into the future?

Step 4: Welcome students to the GLOBE Program

Welcome students to the GLOBE Program. Show the GLOBE overview video if available to provide an introduction to GLOBE. You will find in the Preface to the Teacher's Guide a letter from GLOBE addressed to students. Either read it to them or copy the letter for your students and let them read it quietly. Discuss the program with your students, emphasizing the following points:

- GLOBE, Global Learning and Observations to Benefit the Environment, is one of the first programs to explore the state of the Earth as a biosphere, a living whole with complex interconnecting parts.

Changes in one part of the Earth system, whether it be a decline in soil moisture, an increase in cloud cover or a loss of species diversity, for example, affect changes in other parts of the Earth system.

- The GLOBE Program is worldwide, with scientists doing real research. You might want to read a few selections from the scientists letters at the beginning of the modules as a way to bring them to life in the classroom.
- Students are critically important participants in the GLOBE program. They are working in a global community, providing measurements urgently needed by the scientists and therefore by everyone who wants to understand better how the Earth works. Students contribute their data to the GLOBE databases and share with scientists and with other students throughout the world.
- Every school has a study area, and within that area, several study sites. These are outdoor areas where students will be taking their measurements. They will soon be going out together to describe and set up their sites. Each GLOBE Study Site can be seen as a single, large and intricately connected study area. When studied altogether, using the same instruments, these study areas will yield a portrait of our planet that is both valuable and convincing.

This is an historic program, both for its science and for its education. Each one of us, each teacher, each student, each scientist, has a responsibility and an opportunity to do our best work for one another and for our world.

Our Special Place: The Local View

Purpose

To give students their first experience to observe their GLOBE Study Site, using their senses to obtain a holistic, motivating impression of the study site

Overview

Students go outside and make both large-scale and small-scale observations of a portion of their GLOBE Study Site. After a period of reflection, they transform those observations into representations - sketches, stories or poems. Students compare their area with other classmates', and consider what might explain any differences in the two areas. Students also begin to use their GLOBE Science Notebooks.

Time

One class period

Level

All

Key Concepts

A study site is an organic whole.

The natural world is a rich source of information. You can use your senses to gather important information.

Skills

Increasing awareness of one's own environment

Describing, recording and *creating* a representation based on observation

Materials and Tools

A variety of art materials.

Student notebooks to use as GLOBE Science Notebooks.

Preparation

Select a representative nearby location within your GLOBE Study Site.

Make travel arrangements, if they are needed.

If you have not already done so, create a GLOBE bulletin board area in your school or class. Eventually your students will post a wide range of information on the bulletin board. For this exercise, your students will post their drawings, poems and stories.

Prerequisites

This is best done after the Welcome to GLOBE activity.

Background

Each school in the GLOBE program conducts its observations and measurements in a designated study site. This GLOBE Study Site is a 15 km x 15 km region centered on your school and provides the broad context within which specific study sites are designated for the *Atmosphere, Hydrology, Soil,* and *Land Cover/Biology Investigations*. For more information, please refer to the section Selecting Your Study Sites.

In this activity, your students will explore their GLOBE Study Site with their senses before they begin making multiple measurements. If they start with observing the whole, then they will retain a sense of this larger context within which the parts fit. Furthermore, accurate observation depends on the use of all their senses, not just their eyes. This is particularly true when observing a living eco-system.

This activity has three phases: an observation phase, a reflective phase and a representation phase. During the observational phase, students simply make observations. They record anything and everything they observe within the study site. The observations and recording are done in a stream-of-consciousness fashion to help focus attention on the observable and heighten awareness. During the reflection phase, each student reviews his or her collection of observations and considers how the observations relate to one another. During the representation phase, students create a representation of their site or some aspect of it. This can take many forms - a poem, a detailed drawing, a story. This phase brings together each individual's observations and reflections.

This kind of initial contact with the environment strengthens the student's motivation to learn. With their lively multi-modal sensibility intact, students will observe more keenly, care more deeply, and think more broadly about the particular site. They then will be more committed to subsequent GLOBE protocols and investigations. You might want to repeat this holistic observation periodically and give the students an opportunity to see how their own perceptions grow in depth and breadth.

What To Do and How To Do It

1. Ask each student to select a place within the GLOBE Study Site. This will be their "special place." Ask students to do some of the following exercises. Read each section aloud, asking students first to observe, then to reflect, and then the write or draw in their GLOBE Science Notebooks. Pause between questions for several minutes in order to give your students the appropriate amount of time to observe, reflect and respond.

Have your students do the following:

Observation Phase

2. Sit quietly in your site, experiencing and observing it. Use your senses - your eyes, your ears, your nose - to explore the site. What do you see? What do you hear? What do you smell? What do you feel?
3. Observe the "big picture" about your special place, looking both high enough to include the sky and low enough to see the ground. What are the biggest features you notice?
4. Observe the "small picture" in some detail, the area immediately around you. What do you notice?

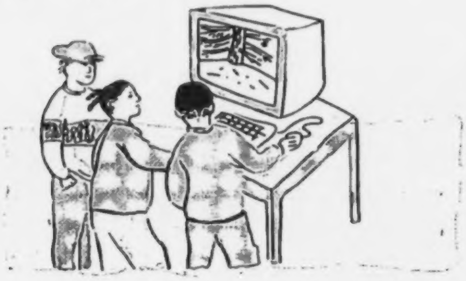
Reflection Phase

5. Think back over your experience. What strikes you most strongly about your observation?
6. How much of what you saw, heard or smelled was man-made? How much is natural? What do you find beautiful? What unattractive? What questions do you have?

Representation phase

7. Sketch a picture, poem or story about your place. Include your feelings about it as well as what you have seen and learned.

When the class returns to the school, have students share their observations, sketches and writing. Post some of them on the school's GLOBE bulletin board.



Extensions

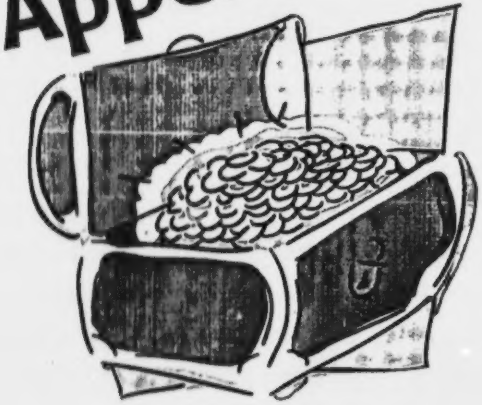
- Create individual and classroom reproductions of the site, or part of the site, in a variety of media: photographic essay, set of drawings or paintings, GLOBE Science Notebook with specimens, mural, diorama, Hypercard presentation, video, storybook, etc. Try to include something about each individual's special site.
- A second field trip could feature comparing one site with another. Students could consider what further exploration might help them learn more about their "special places."
- If you are already on GLOBEMail, have students send the latitude and longitude of the selected site to another school via GLOBEMail. Invite the other site to speculate about your site - what animals and plants live on your site? What typical weather and climate patterns affect the site? What is the local soil and hydrology like? After the first GLOBEMail exchange, give clues about the site, if necessary.
- Research your study area's geological, historical, and legal characteristics. Look at old topographic maps. How might this site have looked five years ago? A hundred years ago? Ten thousand years ago? Describe any changes you think may have occurred during these time spans. Use both words and images to describe these changes. Survey neighbors for tales of the history of your study site.
- Explore the idea that the site may change again. What changes are most likely? Illustrate more than one scenario for what changes may take place during the current year, next year, in 10 years, and in 100 years.

Student Assessment

Have each student create a portfolio of seasonal observations for each site. Then compare and contrast the observations, looking for enhanced understanding. Ask each student to comment on what he or she has learned since the first observation, in contrast with the later observation. (This can tie in with the *Seasons Investigation*, which takes place after your students have begun collecting and submitting GLOBE data.)

Acknowledgment: This activity was inspired in part by TERC's Global Lab Project, *Selecting and Experiencing Your Study Site*.

Appendix



Master List of GLOBE Protocols

Master List of GLOBE Learning Activities

Master List of Science and Thinking Skills

Master List of Key Concepts by Chapter

Glossary

Addresses for Submitting Photos, Maps, and Charts

Master List of GLOBE Protocols

This is a comprehensive list of the measurements your students will take as a part of GLOBE. The protocols are given in each of the investigations.

Atmosphere

Daily

- cloud type
- cloud cover
- rainfall
- solid precipitation
- pH of precipitation
- maximum, minimum, and current temperatures

Hydrology

Weekly

- transparency
- temperature
- dissolved oxygen
- pH
- conductivity for fresh water or salinity for brackish or salt water
- alkalinity
- nitrate

Soil

Daily to Monthly

- soil moisture

Weekly

- soil temperature

Seasonally

- infiltration
- diurnal cycle of soil temperature for two consecutive days

Once at each Soil Characterization Sample Site

- soil profile photograph
- slope
- infiltration
- soil characteristics for each soil horizon
  - depth
  - structure, color, consistence, texture, presence of roots, rocks, and carbonates
  - bulk density
  - pH
  - particle size distribution
  - fertility (nitrate-nitrogen, phosphate, and potassium)

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Land Cover /Biology

Once or twice each year for Biology Study Sites

(once during the peak growing season and once during the adverse season if there is one) and

Once for other Quantitative Land Cover Sample Sites

- Forests and Woodlands
  - canopy cover
  - ground cover
  - dominant and co-dominant species (when trees are fully leafed out)
  - tree height
  - tree circumference
- Grasslands
  - grass biomass

Once only for all Land Cover Sample Sites and Biology Study Sites

- MUC Level 4 land cover classification
- Photographs from the center of the site looking North, East, South, and West

Once for the GLOBE Study Site

- Land cover map using manual interpretation and classification of the hard copy Landsat TM image
- Land cover map using unsupervised clustering with MultiSpec software and classification of the clusters
- Accuracy assessment of each map using validation Land Cover Sample Site data

GPS

Once for the front entrance of the GLOBE school and for each study or sample site

- latitude
- longitude
- elevation

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Master List of GLOBE Learning Activities

Implementation Guide

Our Home Planet
Our Special Place

Atmosphere

Observing, Describing and Identifying Clouds
Estimating Cloud Cover: A Simulation
Studying the Instrument Shelter
Building a Thermometer
Land, Water, and Air
Cloud Watch

Hydrology

Water Walk
Model Your Watershed
Water Detectives
The pH Game
Practicing the Protocols
Water, Water Everywhere
Macroinvertebrate Discovery
Modeling Your Water Balance

Soil

Just Passing Through - Beginners
Just Passing Through
From Mud Pies to Bricks
Soil and My Backyard
A Field View of Soil - Digging Around
Soil as Sponges: How Much Water Does Soil Hold?
Soil: The Great Decomposer
Making Sense of the Particle Size Distribution Measurements
The Data Game

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Land Cover/Biology

- Leaf Classification
- How Accurate is it? Introducing the Difference/Error Matrix
- What's the Difference?
- Odyssey of the Eyes
- Some Like It Hot!
- Discovery Area
- Site Seeing
- Seasonal Changes in Your Biology Study Sites

GPS

- What is the Right Answer?
- Relative and Absolute Directions
- Working with Angles
- Celestial Navigation

Seasons

- What Can We Learn About Our Seasons?
- What Are Some Factors That Affect Our Seasons?
- How Do Seasonal Temperature Patterns Vary Among Different Regions of the World?
- What Can We Learn by Sharing Local Seasonal Markers with Other Schools Around the World?

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Master List of GLOBE Science and Thinking Skills

Basics:

- *asking*
- *reading*
- *organizing*
- *reflecting*
- *determining*
- *identifying*
- *comparing*
- *brainstorming*
- *estimating*
- *collecting*
- *consolidating*
- *elaborating*
- *categorizing and classifying*

Researching:

- *observing*
- *designing*
- *hypothesizing*
- *describing*
- *interpreting*
- *comparing*
- *predicting*
- *generating questions*
- *analyzing*
- *modeling*
- *drawing conclusions and correlations*

Working with Data:

- *digitizing*
- *mapping*
- *graphing*
- *collecting*
- *recording*
- *organizing*
- *verifying*
- *summarizing*

Working with Instruments and Tools:

- *measuring*
- *calibrating*
- *conducting*
- *reading*
- *comparing and interpreting*
- *manipulating*
- *building*
- *converting*
- *following directions*

Quantitative:

- *laying and plotting*
- *building and modeling*
- *drawing and graphing*
- *measuring*
- *subtracting and adding*
- *solving*
- *manipulating*
- *collecting*
- *testing*
- *converting*
- *averaging*

Communicating:

- *writing reports*
- *speaking orally*
- *interpreting*
- *using graphics*
- *summarizing*
- *describing*

Master List of GLOBE Key Concepts by Chapter

Atmosphere

- Cloud formation
- Composition of the atmosphere
- Cooling/warming effect of clouds
- Condensation
- Effects of wind on precipitation measurement
- Meniscus reading
- Change of state, heat capacity, density of snow
- Heat, temperature, convection, conduction, radiation
- Clouds are identified by their shape, altitude, and precipitation characteristics
- Using a simulation to explore the accuracy of observations
- Heat transfer through radiation, conduction, and convection
- Substances expand and contract as the temperature changes.
- Liquid-in-glass thermometers work on the basis of thermal expansion and contraction.
- Conduction and convection are two key forms of heat transfer.
- Different substances, such as soil, water, and air transfer energy and heat at different rates.
- Relationships of clouds and changes

Hydrology

- Temperature
- Temperature measurement
- Heat, heat transfer, conduction
- Accuracy, precision
- Dissolved oxygen
- Comparing with a standard
- pH and its measurement
- Temperature affects pH
- Calibration
- pH buffers and standards
- Alkalinity
- Natural factors affecting alkalinity
- Standardization
- Conductivity, factors affecting conductivity
- Surface water exists in many forms, such as: ponds, lakes, rivers, and snow cover. Water characteristics are closely related to the characteristics of the surrounding land. Water moves from one location to another. Surface water has many observable characteristics, such as: color, smell, flow, and shape.
- A watershed guides all precipitation and run off to a common watercourse or body of water. The Hydrology Study Site is part of a watershed. The nature of a watershed is determined by the physical features of the land.
- Quality assurance, quality control, reliability, accuracy, protocol, calibration
- Solutions, Suspensions
- pH measurements
- Each organism has a range of water characteristics needed for survival. Some have a wide range of water quality where they can live. These differences dictate adaptability to a changing environment. There are geographical patterns in water quality and annual survivability.

Soil

- Soil horizon, color, texture, root distribution
- Soil measurements may be influenced by external factors such as land use, general climate, parent material and topography.
- Sampling procedures
- pH of soil, particle size distribution, texture
- Soil holds moisture. Water is characterized equally well by its weight as by its volume. Soil moisture increases after precipitation. The amount of increase depends on many factors. Soil moisture decreases on dry sunny days. The rate of soil drying also depends on many factors.
- A soil moisture meter can be used to make an indirect measurement of soil water and content after calibration.
- Soils vary within a small local area. Soil properties are related to the soil forming factors. Soil can be classified according to its properties.
- Soil profiles can be described based on the five soil-forming factors. Soils within a small geographic area show considerable variety. Soil factors also affect soil moisture content and temperature.
- Measuring and recording data accurately. Estimates give a feel and data quality and estimates provide a way to pick out unusual data for further research
- Different objects can hold different amounts of water. When objects dry they release their water. Squeezing and evaporation are two ways to remove water. Soil water content is a measure of the amount of water in a soil sample. Soil water content varies around the world.
- Decomposition in soil depends upon different environmental conditions.

Land Cover/Biology

- Land Cover classes, MUC classification scheme
- Pixel Size, canopy cover, ground cover, tree height and circumference, grass biomass, dominant and co-dominant species
- GPS, field measurements/biometry
- Accuracy assessment allows us to evaluate our ability to map land cover. Once evaluated, accuracy can be improved using the knowledge we gain from the difference/error matrix.
- A map is a symbolic representation of a certain land area. The field of view is how large an area your eye or camera's eye can perceive. The field of view increases the higher the eye is relative to the ground.
- Objects in a remotely sensed image are interpreted and digitized into a code based upon the object's reflectance of bands of light. The image codes are relayed through a satellite dish to a computer for storage or enhancement. Image display is accomplished by conversion of stored data to a user-defined color-coded image.
- Orbiting satellites take photographs with cameras that are sensitive to a variety of different wavelengths. One of the main wavelengths sensed is the thermal radiation. The sensor reads the amount of heat being radiated and makes a picture out of the different values. When students observe something without touching it they are actually using their eyes, ears, nose and skin surface to remotely sense that object.
- Humans have an impact on the amount and type of land cover types. Animals and plants are affected when land cover types change. Humans need to be aware of the impact of land developments.
- Your 30 m x 30 m Biology Study Site can be considered a system. Your system contains certain elements within it such as trees, water, soil, rocks, and animals.

- A system has inputs such as sun's energy, water, carbon dioxide, oxygen, dust, and outputs like water, carbon dioxide, oxygen, heat.
- System boundaries will differ depending upon the question you are asking.
- In the spring, there is a period of bud-break, in which leaf buds appear and grow. In the fall, there is a period of senescence, in which actively growing plant material dies.
- Classification helps us organize and understand the natural world. In order for classification systems to be useful, we need to quantitatively determine their accuracy. Criteria are used to define accuracy levels.

GPS

- Latitude and longitude and mapping
- Relative and absolute direction, latitude and long, angles, use of magnetic compass, basic mapping, spacing
- Angles are measured in degrees, minutes, seconds, and in decimal degrees. GPS receivers use degrees and minutes to measure angles.
- If the latitude and longitude of one location cannot be measured directly, then they can be calculated by determining it's relation to a nearby known location.
- Levels of measurement incorporate degrees of accuracy. There are mathematical techniques for dealing with degrees of accuracy.

Seasons

- Seasonal changes follow an annual cycle. Observable markers indicate transition points in the seasons. Seasonal changes demonstrate the interconnections among earth's systems.
- Seasonal patterns differ based on geographic locations. There is a lag time between the winter solstice and the coldest day of the year. Annual cycles in the seasons change from year to year. Seasonal temperature cycles vary around the world.

Glossary

band

A specific segment within a continuous range of wavelengths or frequencies such as those of electromagnetic radiation.

blue marble

A common term for the Apollo image of Earth and for similar, natural color images of the full disk of Earth taken from space.

browser

Computer software which allows one to access, read, and view World Wide Web pages that conform to the hypertext transfer protocol.

diorama

A three-dimensional model which tells a story or explains a concept.

electromagnetic radiation

Energy propagating in the form of combined, oscillating electric and magnetic fields often referred to by names specific to the different wavelength bands such as gamma rays, x-rays, ultraviolet light, visible light, infrared radiation, radio waves, and microwaves.

false-color infrared

A color image produced using infrared sensitive film or a computer image processed to produce a similar result usually with near-infrared wavelengths appearing red, red wavelengths appearing green, and green wavelengths appearing blue.

home page

A World Wide Web page (or address) that is made available for initial access through Web searches to a set of material or pages.

gravimetric sampling

A method of measurement in which samples are weighed.

inquiry-based approach

An approach to learning which emphasizes students asking questions, developing hypotheses, and designing a methodology to investigate issues or phenomena largely under their own direction.

IR

Infrared radiation.

light waves

Any form of light; the term waves is added to emphasize that light is characterized by its frequency or its wavelength and that light involves oscillations of electric and magnetic fields.

pH

A measure of the acid or base content of a water based on the concentration of hydrogen (H^+) ions. The measurement scale for pH is logarithmic with

$$pH = -\log [H^+]$$

where the square brackets denote concentration in number per cubic centimeter. Pure water and neutral solutions have a pH of 7; acid solutions have a pH lower than 7 (i.e. a hydrogen ion concentration greater than 10^{-7}; basic solutions have a pH greater than 7.

sample sites

Locations where GLOBE measurements are taken only once.

species diversity

The number of different species living in a given area or found in a sample.

spectral pattern

A pattern which characterizes the amount of radiation at each wavelength which is reflected from or absorbed by an object, surface, or gas.

study sites

Locations where GLOBE measurements are taken repeatedly.

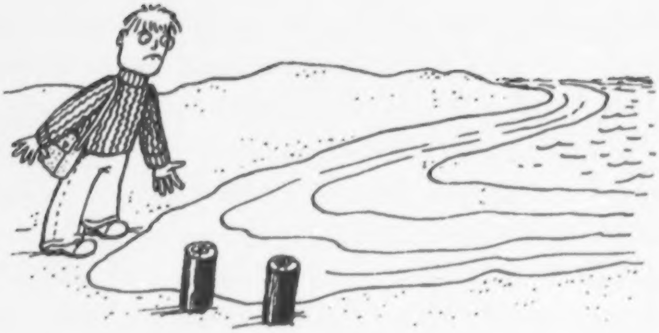
Addresses for Submitting Photos, Maps, and Charts

Mail

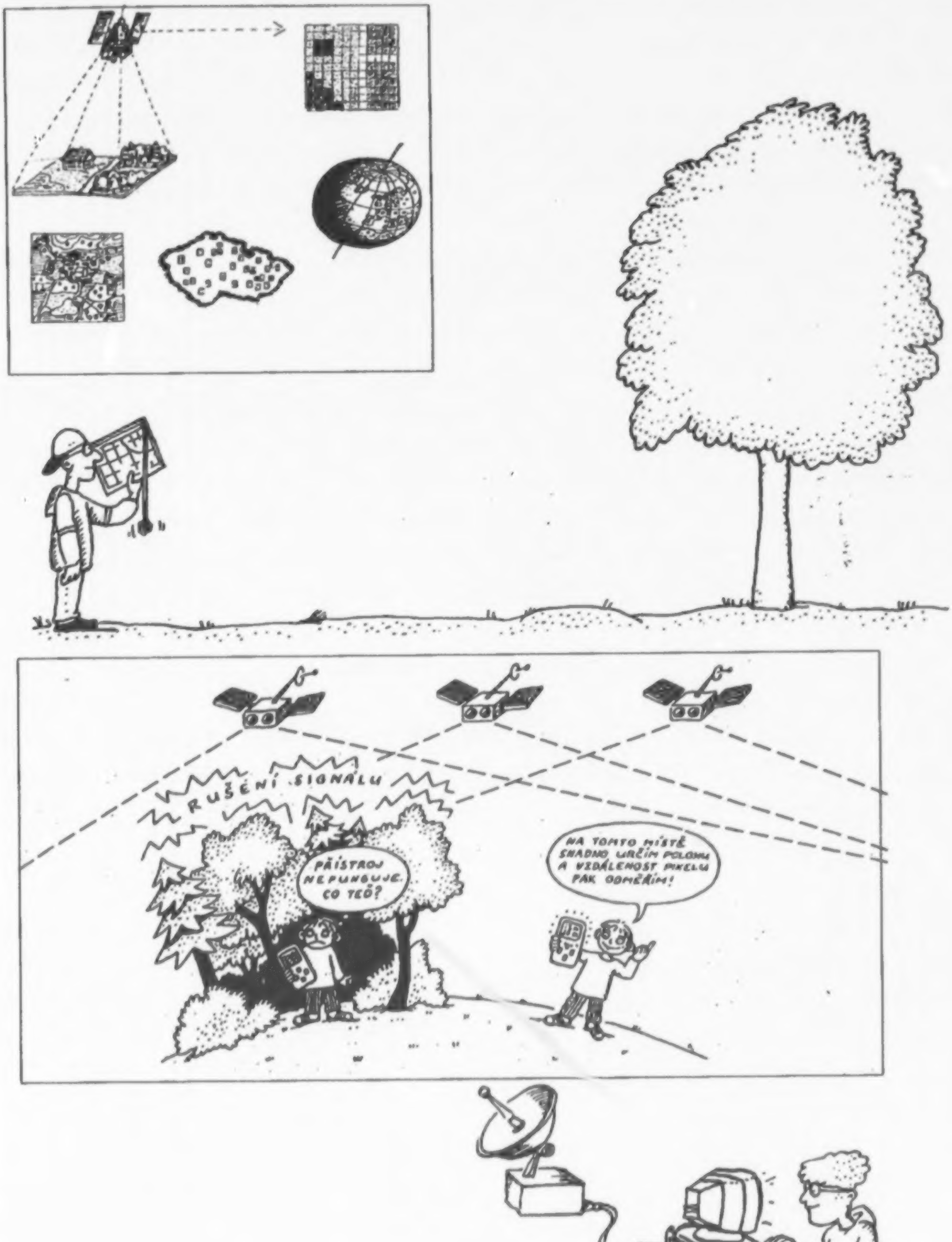
GLOBE Student Data Archive
NOAA/NGDC E/GC 1
325 Broadway
Boulder, Colorado, USA 80303

email

globe@ngdc.noaa.gov



Source: Jan Smolík, 1996, TEREZA, Association for Environmental Education, Czech Republic


RUŠENÍ SIGNALU
PŘÍSTROJ NEFUNGUJE. CO TEĎ?
NA TOMTO MÍSTĚ SNADNO URČÍM POLOHU A VZDÁLENOST PIXELU PAK ODMĚŘÍM!

Source: Jan Smolík, 1996, TEREZA, Association for Environmental Education, Czech Republic

Atmosphere Investigation

GLOBE DATABASE

A GLOBE™ Learning Investigation

Atmosphere Investigation at a Glance

Protocols

Daily measurements within one hour of local solar noon of:

- cloud type
- cloud cover
- precipitation (rainfall or snowfall)
- precipitation pH
- current temperature
- maximum temperature within the last 24 hours
- minimum temperature within the last 24 hours

Suggested Sequence of Activities

Read *Welcome to the Atmosphere Investigation.*

Copy and distribute the scientist letter and interview to your students.

Read through *Protocols* to learn precisely what is to be measured and how.

Read the brief description of the learning activities at the beginning of the *Learning Activities* section.

Do these activities with your students before beginning the protocols:

- *Observing, Describing, and Identifying Clouds*
- *Estimating Cloud Cover: A Simulation*

Install the instrument shelter and the rain gauge in a suitable location on the school grounds. If possible, you should involve your students in planning the location of the instruments. Criteria for placement of the instruments are given in *Protocols.*

Submit your Atmosphere Study Site definition data to the GLOBE Student Data Server.

Make copies of the Atmosphere Data Work Sheet in the *Appendix.*

Teach students how to take the daily measurements, following the instructions in the protocols.

Submit your data every day to the GLOBE Student Data Server.

Do the remaining learning activities as you continue daily measurements.

Special Notes

Make sure you get the instruments required for the Atmosphere protocols. Information on how to obtain these instruments is in the *Toolkit.*

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Student Assessment Introduction-7

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Scientist's Letter to Students

Duplicate and distribute to students.

Dear Students,

Hello! My name is Susan Postawko, and I'm the lead scientist for the Atmosphere and Climate investigations for GLOBE. I'm on the faculty in the School of Meteorology at the University of Oklahoma in Norman, Oklahoma. My partners in the Atmosphere and Climate group here in Oklahoma are Dr. Mark Morrissey, Ms. Renee McPherson, Dr. Ken Crawford, and Dr. Rajeev Gowda. In addition, we have several undergraduate and graduate students working with us. We're very pleased to welcome you to the Atmosphere and Climate investigations, and we're looking forward to working with you.

Nearly everyone on our planet is interested, at some level, in climate and climatic change. This is because any long-term change in temperature or precipitation around the globe will ultimately affect us all. Many countries are implementing education, information, and training programs to increase awareness of the potential impacts of climate change. In order to detect long-term trends, we must improve our monitoring of the global climate.

By making your daily cloud, temperature, and precipitation measurements, you are helping to keep a finger on the pulse of our planet. You are involved in monitoring changes that take place around the world. This is a big responsibility, but one that we are confident you can handle.

When you measure environmental parameters and share your data with students worldwide, you are gaining the knowledge and skills to make choices that will determine what kind of world we leave for future generations.

We will keep you updated on what scientists are learning about our weather and climate, and invite you to send us information about any discoveries you may make!

Again, welcome to GLOBE! And have fun!

Susan Postawko

Dr. Susan Postawko
University of Oklahoma
Norman, Oklahoma, USA

Meet Dr. Susan Postawko

Duplicate and distribute to students.

Dr. Postawko: I'm an assistant professor in the meteorology department at the University of Oklahoma in Norman, Oklahoma. I'm interested in weather around the world as well as on other planets, particularly Mars. I study what happened on Mars during the early history of the solar system and compare it to what Earth might have been like.

GLOBE: *Mars has weather?*

Dr. Postawko: Mars has an atmosphere and any planet with an atmosphere has weather. Its atmosphere is about 1/100th as thick as Earth's atmosphere and its average temperature is below freezing. But when we look at Mars through telescopes, we see cloud patterns that look like cloud patterns on Earth. Shortly after Mars was formed, about 4 billion years ago, it may have been a lot like Earth. We see what look like dried-up river beds on Mars and other indications that water once flowed on its surface. Maybe as recently as three billion years ago, Mars may have been more like Earth. One of the things I'm interested in is if Mars and Earth started out alike, why did they become so different?

GLOBE: *In our solar system does liquid water exist anywhere else other than Earth?*

Dr. Postawko: Maybe on Europa, one of Jupiter's moons. There's compelling evidence that underneath an icy crust, which may be tens of meters thick, there is liquid water on Europa. The reason we think there is liquid water is because Europa is incredibly smooth. Most things in the solar system are pockmarked with craters, but Europa, from what we could tell from the Voyager fly-bys, has a relief of maybe a couple of meters. That's about it. It looks as though when anything higher than that forms on Europa, some liquid from the interior flows upward and fills it in, and since it's icy on the surface, it's pretty certain that the liquid is water.

GLOBE: *So it's kind of like a billiard ball in terms of its surface.*

Dr. Postawko: Yes. The solar system's a fascinating place. You see some of these other places and you ask, 'Wow! How did this happen?'

GLOBE: *What kind of data do you want GLOBE students to collect and why?*

Dr. Postawko: I'm interested in rainfall and clouds because they affect the amount of sunshine that comes in – the sun provides the energy for the whole planet. This is what drives life. We need to know how much sunshine is coming in and what kind of clouds might be reflecting sunlight away. The clouds also tell us about how much water vapor is in the atmosphere and that helps us understand the hydrologic cycle, probably the most critical cycle on Earth. How much water is evaporating from the surface? How much water is in the atmosphere? How much precipitation is there at any point, at any given time?

Everybody talks about global warming these days. The jury is still out on exactly what we are doing to the atmosphere, but the truth is the climate of Earth has always changed. There have been times when it was colder and when it was warmer. We need to understand those changes so we can adjust when new changes come. Are we going to have a new ice age? What's that going to mean about where people can live or the crops we can grow?

GLOBE: *You can identify the trends, but can you identify what causes them?*

Dr. Postawko: Not always. The Earth is a complex system and scientists must know a little of everything—atmospheric science, oceanography, geology, biology, and everything else—to really understand what's causing any one thing to change. For a long time, scientists studied only in their own little niches. It has only been recently that we realized we can't really understand the Earth in parts. So it is more difficult to identify what's causing trends. It seems the precipitation trend probably has to do with the planet getting a little warmer. But then you can ask, 'Well, what's causing it to get a little warmer?' Maybe carbon dioxide is increasing in the atmosphere. Or maybe it's something else.

GLOBE: *Has there been any progress about changing the weather? Making it rain a little more over deserts, for example?*

Dr. Postawko: That's a controversial topic. From the beginning of our awareness of weather, people have tried to change it. We've tried cloud-seeding to make it rain. We've tried seeding hurricanes to help them die out before they hit land. The truth is that in most instances we don't know if what we're doing has any effect. We don't know if seeding clouds really helps them to rain or if they would have rained anyway.

GLOBE: *Have students helped scientists collect this kind of data?*

Dr. Postawko: Absolutely. We're involved in a program where students around the Pacific have been taking rainfall measurements for the last three years. In the Pacific, there's a lot of ocean and not a whole lot of land, so any data we can get from students is invaluable in helping us understand the changes in temperature and precipitation around the region. In fact, students probably make almost 30% of all of the observations that are made around the Pacific.

GLOBE: *Tell us a little about yourself. Where were you born? Where did you grow up?*

Dr. Postawko: I grew up in St. Louis, Missouri and went to college at the University of Missouri in St. Louis. I was really interested in astronomy, so I went into the physics and astronomy program. I was amazingly unprepared to do that! My high school didn't have an extensive math and science curriculum. I'd always liked science, but I never liked math a lot. In college, I saw the applications of math in science and got excited. I enjoyed it to the point where I became a teaching assistant in math, which I never would have dreamed of doing! I ended up getting a bachelor's degree in physics and astronomy. My interest in astronomy focused on planets. As I contemplated graduate school, one of my professors told me to consider atmospheric science programs because they do planetary atmosphere work. Sure enough, I went to the University of Michigan in atmospheric science. I got my Ph.D. in 1983, and then studied the evolution and atmospheres of planets at the University of Hawaii. In 1991, my husband and I came to the University of Oklahoma and now I'm in a very traditional meteorology department, which is fun. As soon as the weather turns bad, everybody runs to their cars to chase tornadoes.

GLOBE: *You chase tornadoes?*

Dr. Postawko: They chase tornadoes. I still have this urge to go into the cellar when there's bad weather. Everybody else here runs to their cars. The graduate students are threatening to drag me out with them one of the these days. Everybody and his dog has a video camera. I'll watch it on TV.

GLOBE: *What happens when a tornado starts chasing you?*

Dr. Postawko: Then you have basic problems.

GLOBE: *Do you have any children?*

Dr. Postawko: No, but I have four dogs, five cats and three birds.

GLOBE: *What do you do for fun?*

Dr. Postawko: A lot of my fun tends to be in science. I like to go out in the evenings with binoculars and look at the constellations, watch for shooting stars, try to find the planets. My idea of fun has changed dramatically since we've moved to Oklahoma. In Hawaii, I liked hiking, kayaking, and scuba diving. Not much scuba diving in Oklahoma. But, it's an interesting state otherwise.

GLOBE: *You became interested in astronomy in high school?*

Dr. Postawko: I've been interested in astronomy for as long as I can remember. I think in part it was because my dad was interested in looking at the constellations. He'd read to me about planets and things.

GLOBE: *What were your attitudes towards science in middle school and high school?*

Dr. Postawko: I enjoyed science. I struggled through math because I didn't

understand its usefulness. At college, I got a little blue-haired lady for an advisor. When I told her that I wanted to major in physics and astronomy, she said, 'Honey, you know that takes a lot of math.' 'Okay, I guess I'll take a lot of math if that's what I have to do.' She thought I wanted to major in Spanish because I took Spanish in high school. 'No, I don't think I want to major in Spanish.'

GLOBE: *As a woman, did anyone try to discourage you from pursuing science?*

Dr. Postawko: Only that advisor. I don't think she had many women in science. The truth is when I hear women talk about the obstacles they were up against, I really admire them for continuing because I never perceived anybody trying to keep me from doing what I wanted to do. My parents always encouraged me to do what I wanted to do. I had marvelous professors who never implied that I should do something else instead of science.

GLOBE: *If a genie suddenly appeared out of a lamp and offered to answer any question, what would you ask?*

Dr. Postawko: What was early Mars like? I've spent years trying to figure that out.

GLOBE: *Can we find out without actually going there, or do we have to go there and do some digging?*

Dr. Postawko: I think ultimately it's going to mean going there. Part of the problem with sending remote instruments is that they can't see something that looks unusual and test it. One of the ways we learned so much about the moon was the astronauts there could actually look around and determine what to study.

GLOBE: *As a scientist, do you recall the greatest challenge that you met?*

Dr. Postawko: The fascinating thing about science is that almost every day you're doing something that no one else has done before. You're learning new things that no one else has learned before. The exciting thing about science is not just big discoveries that you might be fortunate enough to stumble upon, but that every day you're adding to knowledge.

GLOBE: What are the rewards of science?

Dr. Postawko: I think there are two things in science that can be gratifying. The first is finding out things that help people in their daily lives. Look around at the technologies we use daily. They're offshoots of somebody's science research. There is also gratification in learning and adding to the knowledge about the Earth, the planets, and the universe. You never know what information might help a future generation. When Isaac Newton was coming up with calculus or the theory of gravity, I don't think he really knew how it would be applied in later generations, but now we use that to send spacecraft to Jupiter.

GLOBE: When you were growing up, did you have heroes?

Dr. Postawko: Astronauts. I wanted to be an astronaut. I thought they were the coolest people around.

GLOBE: Do you have any advice for students who are interested in Earth science?

Dr. Postawko: Have confidence in yourself. Do what you want to do. Don't let anybody tell you that you're not smart enough to do something, because if I can get through this, anyone can. You have to follow your heart, you have to follow what you're interested in doing. If you really put your mind to it, you can do it. That sounds corny, and if somebody had told me that as an eighth grader, I would have said, 'Yeah, right, sure. You don't know what it's like.' But it really is true.

GLOBE: Do you have anything else you want to add?

Dr. Postawko: I hope that students do not think that scientists sit in ivory towers with no connection to the real world. The real world is science. Science is like a mystery novel. You're always looking for answers. Why did this happen and why did that happen? Students should have fun with science.

Introduction

Atmosphere

The Big Picture

"Everybody talks about the weather but no one does anything about it!" This is an old cliché that has been a complaint of people all over the world, probably for centuries. Actually, someone is doing something about the weather. Scientists around the world are studying the weather everyday, and now through GLOBE, your students can help! The measurements they make will help us better understand our planet's climate.

There are many reasons why we study the atmosphere. On a day-to-day basis we want to know things like what the temperature will be so we can decide what type of clothes to wear; whether we need to take an umbrella with us when we go outside; or if we need to wear a hat and sunscreen to protect us from the sun's ultraviolet rays. Farmers need to know if their crops will get enough rain. Ski resorts need to know if enough snow will fall. People in areas struck by hurricanes would like to know how many hurricanes to expect in a given year. Nearly everyone would like to know what the weather is going to be, not only tomorrow or the next day, but six months, a year, or even ten years from now! Atmospheric scientists study not only what is going on with the world's weather today, but why it was a certain way in the past and what it will be like in the future.

By *weather* we mean what is happening in the atmosphere today, tomorrow, or even next week. By *climate* we mean weather over time. For example, in a certain city the current temperature may be 25° C (this is weather), but if we were to look at the weather records for the past 30 years we might find that the average temperature in that city on that particular day is 18° C (this is climate). We also might find that over this 30 year period the temperature in this city has ranged from as high as 30°C to as low as 12°C on that particular day. Therefore, the present temperature of 25°C is not unusual.

When we study the history of Earth's climate, we notice that temperature and precipitation in any given region change over time. For example, images from certain satellites show that great rivers used to run through the Sahara Desert. We also believe that ice caps once covered parts of Africa and that a shallow sea covered much of the United States. All of these changes happened long before people lived in any of these regions. If Earth was so different in the past, can we predict what might happen in the future?

Earth's atmosphere is a thin layer of gases made up of about 79 percent nitrogen, 20 percent oxygen, and 1 percent of a number of other gases (including water vapor and carbon dioxide). The atmosphere is quite active and changes in one part of the world are likely to result in changes in other areas. Many scientists are concerned that burning fossil fuels, such as coal and oil, puts so much carbon dioxide into our atmosphere that it may warm the entire planet. Burning also adds particles called *aerosols* to the atmosphere and locally these aerosols can more than offset the warming effects of carbon dioxide and other gases. Burning fossil fuels can also increase the amount of gases such as sulfur dioxide and nitrogen oxides in the atmosphere. Increases in these gases have been linked to increasing acidity of precipitation, which can affect plants, animals, water supplies, soils, and structures. Although Earth's climate varies naturally, humans have the potential to affect the climate at a much faster rate than natural changes take place.

The consequences of climate change potentially could affect every living thing on our planet. International communication and cooperation is vital to understanding and coping with the possible effects of global climate change. Measurements of environmental parameters are necessary to monitor the present state of the atmosphere and alert us to any changes that might be taking place. Through the GLOBE program, students will help scientists to understand environmental conditions on Earth today and over time, to determine if there are any changes.

People often think that scientists know what is happening in all parts of the world, but this is far from true. There are many regions where scientists have only the most general understanding of environmental factors such as temperature and precipitation. Even in regions where there seems to be an abundance of data, scientists still do not know how much these factors vary over relatively short distances. The measurements that students make through the GLOBE program will go a long way in helping everyone understand more about the world.

A Field View of the Atmosphere Investigation

Although there are many aspects of the atmosphere that are important to understand, the fundamental measurements on which we will focus are cloud type and cover, air temperature, and precipitation amount and pH. A great habit to develop is looking up at the sky every time you go outdoors. Start to pay attention to what is going on in the atmosphere. You might be surprised at how much is happening!

Students will make cloud observations with their eyes. One quantity they will estimate is cloud cover, which ranges from zero (a totally clear sky) to 100 percent (a completely overcast sky).

Another characteristic students will determine with their eyes is cloud type. Scientists have defined classes of clouds based on their appearance and their altitude. Students may already be familiar with some cloud types, like tall thunderclouds called cumulonimbus, or the wispy ice clouds high in the sky called cirrus. With the help of the GLOBE cloud chart, students will categorize each cloud as one of ten types.

The basic instrument for measuring temperature is the thermometer, of which there are many types. Special thermometers are available that register maximum and minimum temperatures, that is, the highest and lowest temperatures since the last time the thermometer was reset. To measure the temperature of the air, a thermometer should be located in a well ventilated place out of direct sunlight and away from local sources of heat.

Precipitation is relatively easy to measure. The rain gauge is a simple container to catch rainfall, combined with some means for determining how much water has accumulated in it. It is important that the gauge be located in an area that is not blocked by buildings or covered with trees, as these would influence the amount of rain that could fall into your gauge. In regions where snow falls, snow depth can be measured with a meter stick. Water content varies greatly from snowfall to snowfall, and therefore it also needs to be measured. The pH of rain water or melted snow can be measured using pH paper, a pH pen, or a pH meter, depending on the level of the students.

Prior to the actual placement of the instruments used in this investigation, read the section on instrument placement in the Protocols section. Then, with your students, take a walk around the school grounds to locate the best places to site the instruments. This activity will help assess the students' initial knowledge and will get them thinking about the factors that can influence their measurements.

Good questions to help get the students started on determining the best places to take their measurements would be:

- Where on the school grounds would you see the most clouds? Where would you see the least?
- Where on the school grounds would the temperature be the highest? Why? Where would temperature be the lowest? Why? Are either of these two areas representative of the entire school grounds?
- How could buildings affect the temperature?
- Would there be a difference in temperature between a grassy field and a paved parking lot or playground? Why?
- Where would you put a rain gauge to catch the most rain? Why? Is this the same place where you would place a board to catch the most snow?

As you walk around the school grounds, have the students draw a map of the area. The youngest students could just sketch the main features, such as the school building(s), parking lots, playgrounds, etc. Older students should fill in more detail, such as what the playground surface is (e.g. paved, grassy, or bare ground). Have them note any streams or ponds and indicate areas of trees. They could measure the heights of buildings and trees using the clinometer and techniques given in the *Land Cover/Biology Investigation* and note these on their maps. The goal is to have a drawing of the school grounds so that when you decide where to place your meteorological instruments, students can locate them on their map. This will allow the students to give a good physical description of the area surrounding their instruments. In subsequent years, the new class of students can repeat this mapping to understand why the specific locations were chosen.

Focusing on the Key Science Ideas

In this section we will look more closely at the scientific importance of each of the atmospheric measurements that will be made as part of the GLOBE program.

Clouds

Water is present in the atmosphere in the form of gas (water vapor), liquid (rain drops or cloud droplets), and solid (ice crystals or frozen rain). Like most other gases that make up the atmosphere, water vapor is invisible to the human eye. However, unlike most other gases in our atmosphere, under the right conditions water vapor can change from a gas into solid particles or liquid drops. If temperatures are above freezing, the water vapor will condense into cloud droplets. If temperatures are below freezing, as they always are high up in the atmosphere, tiny ice crystals will form instead. Clouds are simply the visible form of these crystals or droplets.

Which types of clouds you see often depends on the weather conditions you are experiencing or will soon experience. Some clouds form only in fair weather, while others bring showers or thunderstorms. The types of clouds present provide important information about vertical movement of the atmosphere at different heights. By paying attention to the clouds, soon you will be able to use cloud formation to forecast the weather!

Everyone is aware of clouds, but not everyone is aware of their importance to weather and climate. Clouds play a complex role in the climate system. They are the source of precipitation, affect the amount of energy from the sun that Earth absorbs, and insulate the Earth's surface and lower atmosphere. At any given time, about half of Earth's surface is shadowed by clouds. Clouds reflect some of the sunlight away from Earth, thus keeping the planet cooler than it would be otherwise. At the same time, clouds also absorb some of the heat energy given off by the Earth's surface and release some of this back toward the ground, thus keeping the surface warmer than it would be otherwise. Satellite measurements have shown that, on average, the cooling effect of clouds dominates over their warming effect. Scientists calculate that if clouds never formed in Earth's atmosphere, our planet would be nearly 30° C warmer on average.

Question for discussion: Find out the average number of sunny days in each month for your area, as well as the average temperature for each month (consult an almanac or similar reference book, or conduct a search on the World Wide Web; after the first year, use your GLOBE data as well). How do students think the temperature of your area would be affected if the number of sunny days increased or decreased?

Precipitation

Another vital measurement students will make is *precipitation*. Precipitation refers to all forms of liquid or solid water that fall from the atmosphere and reach Earth's surface. *Liquid precipitation* includes rainfall and drizzle, *solid precipitation* includes snow, ice pellets, hail, and freezing rain.

Our planet is a water planet. In fact, it is the only planet in our solar system where liquid water naturally flows on the surface. Nearly all life depends on water. The water that ends up in the atmosphere, only to be returned to Earth's surface, is a part of the larger *hydrologic cycle*. In this cycle, water evaporates from the oceans and land, passes through the atmosphere, falls to the surface as precipitation, and returns to the sea from the land through rivers and other paths.

Precipitation is a vital component of climate. Where it is scarce, deserts occur. Where it is abundant, there is luxurious plant growth. Water sustains life. Precipitation is critical to agriculture, fresh water supplies, and, in some regions, power supplies.

One of the key roles of water on Earth is to transfer heat from the *tropics* to higher latitudes. This is done both by the movement of ocean waters (currents) and by the movement of water in the atmosphere. As energy from the sun reaches Earth's surface, it is more intense near the equator than it is near the poles. That is the main reason why it is warm in the tropics and cold in the Arctic and Antarctic.

Much of the sun's energy in the equatorial regions is absorbed by oceans, causing water to evaporate. This water vapor is now free to move in the atmosphere. As it moves upward or towards higher latitudes, the water vapor encounters colder temperatures, and it begins to condense (change from a gas to a liquid) and form clouds and precipitation. When water changes from a gas to a liquid, it releases heat into the atmosphere. In other words, through the transformation of water from a liquid to a gas, then back to a liquid in the atmosphere, some of the sun's energy is transported from the equatorial regions towards the polar regions.

By knowing where clouds form, and where, when, and how much precipitation falls, scientists can better understand where energy is being released or absorbed in Earth's atmosphere. This, in turn, helps scientists understand the behavior of Earth's atmosphere.

Question for discussion: Find out the average amount of precipitation in your area for each month (consult an almanac or similar reference book, or conduct a search on the World Wide Web; once you have GLOBE data for at least a year, include this as well). What do you think would happen if all the precipitation occurred in just one month? What would be the consequences if the rain were evenly distributed throughout the year? What if you got only half the amount of rainfall in a given year? What if you got double the amount of rainfall? What factors do you think influence where and when rain falls?

Precipitation pH

Water moves through every living plant and animal. The chemical composition of the water, therefore, will affect all terrestrial and aquatic ecosystems. Although normal precipitation is slightly acidic (pH of about 5.6) due to the gases which naturally comprise Earth's atmosphere, burning of fossil fuels releases gases into the atmosphere which interact with water vapor and form precipitation with pH below 5.6. This *acidic precipitation* can directly harm plants over a long period, but its most serious effect is weakening plants so that they become more susceptible to stresses such as cold, disease, insects, and drought. Acidic precipitation leaches nutrients out of the soil and also can release from the soil soluble aluminum ions which damage tree roots. If these aluminum ions are washed into lakes and streams they can harm many kinds of fish.

In addition to adversely affecting life forms, acid precipitation does great harm to structures. Acid precipitation is known to enhance corrosion of metals and contributes to the destruction of stone structures and statues. In many regions of the world, famous buildings and sculptures are deteriorating at increased rates.

The acidity or pH of water can change as it moves through the environment. When water first condenses in the atmosphere, its pH is neutral or 7.0. Then, gases such as carbon dioxide and particles from the atmosphere dissolve in the water droplets, usually lowering the pH. As water flows over the land surface or through soil, the pH is changed by chemical interactions with the land. The water then comes together in streams, rivers, lakes, and eventually the oceans. In GLOBE, students measure the pH of precipitation, soil, and surface water.

Temperature

When we think of the difference between day and night, between winter and summer, or between the climate of a tropical region compared to a polar region, we can easily imagine these differences in terms of temperature.

Many factors affect temperature. One of the most important factors is latitude. Scientists studying the climate of our planet are very interested in finding out if the temperature at different latitudes is changing, and if so, is it changing in the same way at all latitudes? Most computer models of Earth's climate predict that if Earth warms then the polar regions will warm more than the tropics (although the polar regions will always remain colder than the tropics).

Together, temperature and precipitation have an important impact on the types of plants and animals that live in a certain area, and even on what kind of soil forms there. The measurements that students make for the GLOBE Atmosphere Investigation are important to scientists who study weather, climate, land cover, biology, hydrology, and soil.

Questions for discussion: Find out the average temperature for your area for each month (consult an almanac or similar reference book, or search the World Wide Web; once you have GLOBE data for at least a year, include this as well). Is there a variation in temperature from month to month? If so, why do you think this happens? Do you think that all places at your same latitude experience the same temperature? Why or why not? What factors do you think most affect the temperature in your area?

Preparing for the Field

Choosing the location for your Atmosphere Study Site and setting up your rain gauge and thermometer shelter at this site will be your single most time-consuming task in this investigation. See the *Protocols* for complete instructions on choosing the site and proper placement of the instruments. Daily readings of precipitation amount and temperature typically will take less than 10 minutes (perhaps a bit longer for the youngest students who may need more time to study the numbers). The cloud observations may take 5 minutes or so per day, depending on how much class discussion there is on the cloud cover and cloud types. Expect the cloud observations to take longer when the students are first learning how to take them. Again, the youngest students may need more time. Depending on the method used to take precipitation pH measurements, this protocol will take from 5 to 15 minutes (longer if the pH pen or meter has not been calibrated recently).

All of the atmospheric science measurements need to be taken on a daily basis, as close to the same time of day as possible, to ensure easy comparison of measurements made around the world. For GLOBE, all atmospheric observations should be made within one hour of local solar noon, and the rain gauge should be emptied and the thermometer reset during this two hour period as well. See the box on how to calculate solar noon. Does this mean that only classes that meet at that time can participate? NO! Because these measurements do not require much time to take, students from classes that meet earlier or later in the day can be assigned to take the measurements during their lunch break. The key is consistency in the time of day the measurements are taken.

A single student can read the rain gauge and the thermometer. However, it is a good idea to have a small group of students take these readings so they can check each other. Readings could either be taken by the group as a whole, or readings could be made individually and then compared. If the readings are made individually, the group must remember to empty the rain gauge and reset the thermometer when they are finished. Rotating groups through the class (or classes) on a daily or weekly basis will give all students an opportunity to participate. Having multiple groups take measurements at different times on the same day is discouraged because it opens the door to confusion in emptying the rain gauge, resetting the thermometer, and reporting the data. Remember that when GLOBE gets a second data report for the same Atmosphere Study Site on the same day, the second report is viewed as a correction and replaces the first one.

The estimates of cloud type and cloud cover are *subjective* measurements, so the more students involved in this task, the better. Each student should take his or her own readings; then, students should come to an agreement as a group. Do not be surprised if your students initially have difficulty with these estimates. Even seasoned weather observers debate which type of cloud they are seeing, or exactly how much of the sky is covered by clouds. As your students get used to these observations, they will begin to recognize the subtle differences in cloud types.

How To Calculate Solar Noon

Solar noon is the time when the sun appears to have reached its highest point in the sky during the day. Solar noon is the term used by GLOBE. An astronomer, for example, would refer to the same time as local apparent noon. Solar noon generally is not the same as "clock noon," and depends on your location within your time zone. Solar noon does occur, however, half-way between your local sunrise and sunset. Therefore, an easy way to calculate your local solar noon is to find a newspaper from a nearby town that gives sunrise and sunset times. Take the average of these times to find solar noon. First, convert all your times to 24-hour clock times by adding 12 to any pm times, then find the average of the sunrise and sunset times. (Add the two times and divide by two.) This is the time of solar noon.

Example:	1	2	3	4
Sunrise (am or 24-hour clock are the same)	7:02 am	6:58 am	7:03 am	6:32 am
Sunset	5:43 pm	5:46 pm	8:09 pm	5:03 pm
Sunset (24-hour clock)	17:43	17:46	20:09	17:03
Sunrise + Sunset	24 hr 45 min	23 hr 104 min	27 hr 12 min	23 hr 35 min
Equivalent (so that the number of hours is even)	(unchanged)	24 hr 44 min	26 hr 72 min	22 hr 95 min
Divide by 2	12 hr 22.5 min	12 hr 22 min	13 hr 36 min	11 hr 47.5 min
Local Solar Noon (rounded to the nearest minute	12:23 pm	12:22 pm	1:36 pm or 13:36	11:48 am

Overview of Educational Activities

Student Learning Goals

Within GLOBE, students can enhance their education through involvement in hands-on, scientifically valid research. Student learning goals for this module are:

- To observe and measure weather and climate-related phenomena accurately and objectively,
- To design and test students' own weather instruments as a way of understanding how standard instruments work,
- To classify objects and events based on similarities, differences, and interrelationships,
- To solve problems by experimentation,
- To interpret collected data and come to sound conclusions,
- To explore and understand the uncertainties inherent in any scientific measurement,
- To communicate information learned through their scientific investigations, and
- To develop models from data, patterns, or relationships.

Concepts

The concepts which are covered in the protocols and learning activities of this investigation are:

Composition of the atmosphere
Cloud formation
Condensation
Cooling and warming effects of clouds
Clouds are identified by their shape, altitude, and precipitation characteristics
Relationship of clouds and changes in clouds to weather
Effects of wind on precipitation measurement
Change of state
Density of snow
Factors affecting the pH of precipitation
Temperature
Heat
Convection
Conduction
Radiation
Heat transfer through radiation, conduction, and convection
Conduction and convection are two key forms of heat transfer
Different substances, such as soil, water, and air, transfer energy and heat at different rates
Heat capacity
Substances expand and contract as the temperature changes
Liquid-in-glass thermometers work on the basis of thermal expansion and contraction
Using a simulation to explore the accuracy of observations
Meniscus reading

Student Assessment

Students should be assessed using formative and summative evaluation methods, which may be either qualitative or quantitative in nature. Such methods should reflect the development level of your students. Various tools should be used to assess the growth of students in the following areas:

- concept mastery
- use of science process skills
- attitudes toward science, science classes, and science careers
- higher level skills, including questioning, identifying cause and effect, and predicting
- applying concepts and process skills in new situations

One way to assess students' understanding of the content and processes within the Atmosphere Investigation is to monitor the daily data that students record and submit. Is the maximum temperature recorded always greater than the minimum temperature? Is the current temperature recorded equal to or between the maximum and minimum for the past 24 hours? In both instances, the answer should be yes. If it is not, you should suspect that either the students do not know how to read the maximum/minimum thermometer or they are unsure of what they are reading.

Another way to assess students' understanding of the protocols is to ask them to choose the optimum placement for instruments when presented with a variety of situations. What if your school were in a city? What if it were in a heavily wooded area?

The learning activities in this module are designed to help students understand the protocols and the instruments used to implement the protocols. They also allow you to assess students' understanding of key concepts and skills. Students may keep a log of their activities, give oral reports to the class (or maybe even weather reports to the school!), and write papers that could be reviewed by other students.

Skills

The skills covered in the protocols and learning activities of this investigation are as follows:

Broadly Applicable Science Skills

Observing carefully
Observing systematically over a period of time
Measuring
Reading a scale accurately
Collecting and *recording* data
Conducting an experiment
Constructing an apparatus for an experiment
Hypothesizing and *predicting*
Designing experiments
Organizing data in tables
Analyzing data
Graphing
Correlating one observed phenomenon with another
Communicating experimental results orally and in writing
Communicating mathematically
Working effectively in a group

Specific Skills Associated with the Atmosphere Investigation

Estimating simulated cloud cover
Estimating cloud cover
Observing and *describing* the appearance of clouds
Estimating cloud height
Identifying the ten major cloud types
Recording and *organizing* cloud data in the GLOBE Science Notebook
Using a rain gauge
Using a thermometer
Using pH measuring equipment

Protocols

All of the measurements below should be taken daily within one hour of local solar noon.

Cloud Type Protocol

Students will determine the types of clouds in their skies.

Cloud Cover Protocol

Students will determine the cloud cover in their skies.

Rainfall Protocol

Students will use a rain gauge to determine liquid precipitation at their study site.

Solid Precipitation Protocol

Students will measure snow and other forms of solid precipitation at their study site.

Precipitation pH Protocol

Students will measure the pH of rainfall and melted snowfall at their study site.

Maximum, Minimum, and Current Temperatures Protocol

Students will measure air temperature at their study site.

How to Perform Your Atmosphere Investigation

Study Site for the Investigation

Locate the Atmosphere Study Site on or near your school grounds so students can have daily access to them. The precipitation measurements should be taken within 100 meters of the soil moisture measurements described in the Soil Investigation.

Cloud Observation

Measurements of cloud amount and cloud type require an unobstructed view of the sky. The middle of a sports field would be an excellent location. The site where you take your cloud measurements does not have to be in the exact location of your rain gauge and thermometers. To pick a good spot from which to take cloud measurements, simply walk around your school until you come to an area where you have the most unobstructed view of the sky.

If you live in a city, you may not be able to find a completely unobstructed view of the sky. To test whether the site you pick is a good one, ask yourself what would happen if the parts of the sky you cannot see were completely cloud covered or completely clear. Would this make a difference in the measurements you report? A site is satisfactory if a small portion of the sky is blocked, as long as that portion would not change the measurements you report.

Instrument Placement

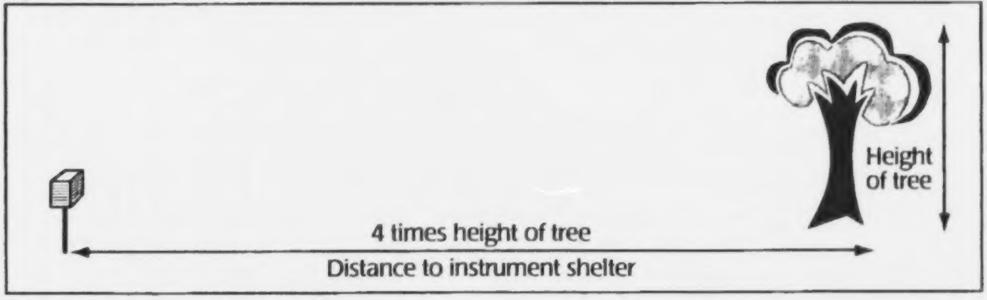
The ideal placement for both the rain gauge (and/or snowboard) and the instrument shelter, which will house the thermometers, is a flat, open area with a natural (e.g., grassy) surface. Avoid building roofs and paved or concrete surfaces if at all possible; these can become hotter than a grassy surface and affect temperature readings. Hard surfaces can cause errors in precipitation measurements due to splash-in. Also avoid placing the instruments on steep slopes or in sheltered hollows unless such terrain represents the surrounding area.

Do not place the rain gauge and instrument shelter close to buildings, trees, or high bushes. Nearby objects can block the flow of air to the thermometers and affect the amount of rain that collects in the rain gauge.

Ideally the rain gauge and the instrument shelter should be placed four times as far from an object as that object is high. For example, if your site is surrounded by trees or buildings that are 10 meters tall, place your instruments at least 40 meters from these trees. See Figure ATM-P-1. At such distances, trees, bushes, or buildings can break the wind and actually make your rainfall readings more accurate.

The instruments may be placed on a single post with the rain gauge on the opposite side from the shelter and above it, so that the instrument shelter

Figure ATM-P-1



does not block rain from collecting in the rain gauge. However, wind is one of the greatest contributors to errors in rain gauge measurements (wind blowing across the top of the gauge creates an effect that causes raindrops to be deflected around the gauge), and where possible, it is best to place the gauge as low to the ground as practical. This requires that the rain gauge be mounted on a separate post 3 to 4 meters away from the instrument shelter so that the instrument shelter does not block rain from collecting in the gauge. The instrument shelter should be mounted on the side of the post away from the Equator (i.e. on the north side in the Northern Hemisphere and on the south side in the Southern Hemisphere).

Your students should draw a map of the locations of the instruments. Include their placement relative to nearby buildings, trees, and shrubs using north-south coordinates as well as their distances to these objects. Also note the type of surface on which the instruments are placed. If it was not possible to locate your instruments as far from buildings, trees, or shrubs as requested or if the area around the instrument shelter is not a grassy natural surface, information about the relative locations of possible obstructions and about the surface material should be reported to the GLOBE Student Data Server as part of defining your Atmosphere Study Site.

Snowboard Placement

Place the snowboard on relatively level ground where the snow depth best represents the average depth of the surrounding area. For a hillside, use the slope with an exposure away from the sun (this means a northerly exposure in the northern hemisphere and a southerly exposure in the southern hemisphere). The site should be free from trees, buildings and other obstructions that may affect wind flow or the melting of snow.

Determine Location

Once you have chosen the site for the instruments, determine its coordinates with the GPS receiver and submit your findings to the GLOBE Student Data Server.

There may be no such thing as an ideal location for the atmospheric instruments on your school grounds. In this case, make every effort to place the instruments in as good a location as possible, and report all derivations from the specified ideal (e.g. only 20 m away from 30 m tall trees, instrument shelter is set up over asphalt).

Note: Some schools may prefer to use automated instruments to measure temperature. Information about the instruments used must be reported to the GLOBE Student Data Server as part of defining your Atmosphere Study Site. Automated instruments require periodic recalibration. If your school uses an automated instrument, you must check its accuracy monthly by comparing it to the readings produced by an instrument which meets the GLOBE Instrument Specifications and which is located as close as possible to the sensors of your automated system.

Cloud Type Protocol

Purpose

To observe cloud type at the school's Atmosphere Study Site

Overview

Cloud type is useful in climate studies and is related to precipitation and air temperature.

Time

5 minutes

Level

All

Frequency

Daily within one hour of local solar noon

Key Concepts

Cloud formation
Composition of the atmosphere
Cooling/warming effect of clouds

Skills

Identifying cloud type
Recording data
Observing carefully

Materials and Tools

Atmosphere Investigation Data Work Sheet
GLOBE Cloud Chart
Observing Cloud Type (in the *Appendix*)

Prerequisites

None

How to Observe Cloud Type

From your cloud-type observation site, examine the clouds in the sky. Refer to the GLOBE cloud chart and the definitions found on the *Observing Cloud Type* sheet in the *Appendix* to determine the cloud type(s) present. Check a box on the Atmosphere Data collection sheet for each cloud type that you observe. Do *not* estimate the amount of each cloud type.

Note: In some instances, it may be difficult to distinguish between cloud types (e.g. altocumulus versus cirrocumulus). In these cases, students should use their best judgement and note their uncertainty in the comment section and in their GLOBE Science Notebooks.

Data Submission

Report the following to the GLOBE Student Data Server:

Date and time of the cloud-type observation in Universal Time (UT).

Cloud type(s) observed (you can report more than one cloud type).

Universal Time

A simple way of thinking about Universal Time (UT) is to ask "What time (on a 24 hour clock) is it now in Greenwich, England?" Since Greenwich is on the line of zero longitude, this is a starting point for the global day. At midnight in Greenwich, the UT is 0:00. In recent history, UT was called GMT for Greenwich Mean Time.

Cloud Cover Protocol

Purpose

To observe cloud cover at the school Atmosphere Study Site

Overview

Cloud type is useful in climate studies and is related to precipitation and air temperature.

Time

5 minutes

Level

All

Frequency

Daily within one hour of local solar noon

Key Concepts

Cloud formation
Composition of the atmosphere
Cooling/warming effect of clouds

Skills

Estimating cloud cover
Recording data
Observing carefully

Materials and Tools

Atmosphere Investigation Data Work Sheet

Prerequisites

None

How to Observe Cloud Cover

Take the cloud cover measurements at the same site and time as the cloud-type measurement. Cloud cover should be reported according to the following cloud-cover classification definitions:

Clear

The sky is cloudless or clouds cover less than one-tenth of the sky. (Since a clear sky can include some clouds, it is possible to report cloud type even when you report a clear sky.)

Scattered Clouds

Clouds cover one-tenth through five-tenths of the sky.

Broken clouds

Clouds cover greater than five-tenths through nine-tenths of the sky.

Overcast

Clouds cover more than nine-tenths of the sky.

Note: Even experienced observers can have difficulty accurately differentiating between scattered clouds and broken clouds. If you see more blue sky than clouds, then the cloud cover is considered to be scattered. If you see more clouds than you do blue sky, then the cloud cover is broken.

Data Submission

Record on the Atmosphere Investigation Data Work Sheet one of the four categories of cloud cover each day, and report your findings to the GLOBE Student Data Server.

Rainfall Protocol

Purpose

To measure rainfall at the Atmosphere Study Site

Overview

Climate studies and Earth systems studies require accurate, long-term rainfall measurements.

Time

5 minutes

Level

All

Frequency

Daily within one hour of local solar noon

Key Concepts

Condensation
Effects of wind on precipitation measurement
Meniscus reading

Skills

Using a rain gauge
Recording data
Reading a scale

Materials and Tools

Rain gauge
Atmosphere Investigation Data Work Sheet
Pens or pencils
Carpenter's level
Wood post (typically about 10 cm x 10 cm)
Screwdriver
Posthole digger

Preparation

Placement of the rain gauge

Prerequisites

None

Background

Rainfall is defined as the depth of water that crosses a horizontal surface over a given time period. You can determine the rainfall by reading the value in millimeters on the measuring scale that corresponds to the water level. Note that this is an expanded scale (i.e., if you hold a ruler up to the scale on the center tube, the distance between the markings on the center tube are not the same as on the ruler). This is because the collection area of the gauge funnel is 10 times the cross-section area of the center tube. This requires that the markings on the inner tube appear larger so the amount of rain can be read directly from the markings.

How to Place the Rain Gauge

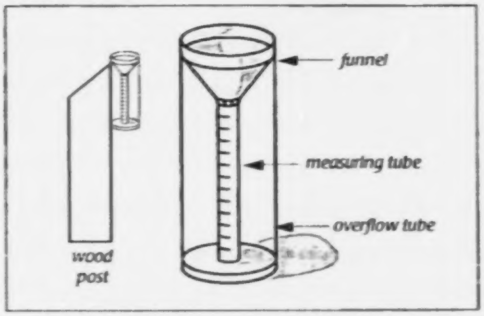
Students will use a standard rain gauge consisting of four parts. See the Figure ATM-P-2.

1. The funnel, which is attached to the measuring tube;
2. The measuring tube, which is a small cylindrical tube having a uniform diameter and a graduated scale located on the side of the tube;
3. The overflow tube, which is a large cylindrical tube designed to catch any overflow of rain during periods of heavy rainfall; and
4. A mounting bracket.

Insert the measuring tube into the overflow tube and then insert the funnel into the measuring tube and the overflow tube.

Fasten the mounting bracket to a wood post having a width approximately that of the rain gauge. Fasten the bracket so that the top of the rain gauge extends 10 cm above the top of the

Figure ATM-P-2



wood post. If possible, cut the top of the post at a 45° angle to lessen the chance that rain will splash into the rain gauge.

The mounted and placed rain gauge should be level. This can be checked by placing a carpenter's level across the top of the funnel in two directions, one crossing the other at right angles.

How to Measure Rainfall

1. Once the rain gauge is located properly, it must be read daily within one hour of local solar noon.
2. When students read the measuring scale, make sure their eyes are level with the water in the measuring tube and that they read the bottom of the meniscus.
3. After each measurement, they should empty the water from the measuring tube into the clean beaker or jar for the pH measurement by inverting the tube and allowing it to drain. Then they should reassemble and remount the rain gauge. Record the date of the measurement, the UT time of the reading, the depth of rainfall in millimeters, and the number of days rain has accumulated on the Atmosphere Investigation Data Work Sheet.

During periods of heavy rainfall, the rain water may exceed the capacity of the measuring tube and flow into the overflow tube. In this case, the level in the measuring tube should be noted and the tube emptied. Then the water in the overflow tube should be measured by pouring the water from the overflow tube into the measuring tube and noting the water level. This may have to be done several times in order to empty the overflow tube. The resulting depths should then be summed to determine the overall depth.

Even if it has not rained, students should check the rain gauge daily to make sure that it is free of debris (windblown leaves, twigs, papers, etc.). Clean the rain gauge after each reading, rinsing it with distilled water.

Bring the rain gauge indoors when the temperature falls below freezing to prevent the plastic gauge from cracking. The overflow tube can be left outside during periods when the daily temperature ranges from above to below 0 °C and both rain and snow are possible.

Data Submission

Report the following information to the GLOBE Student Data Server:

Date and time of day of the data collection (in Universal Time)
Amount of daily rainfall (in millimeters)
Number of days rain has accumulated

For days when there is no rain, place a zero in the *rain water in rain gauge* column. On days when water in the rain gauge is accidentally spilled or the measurement is lost for some reason, enter the letter "M" (for missing) for the daily rain amount. It is important that a missing value is recorded rather than a zero. (It is a common mistake to substitute zeroes for missing values. This leads to erroneous analyses.)

On days when there is rainfall but the amount is less than 0.5 mm, enter the letter "T" (for trace) for the daily rain amount. This tells us that extremely light rainfall occurred. For some research it is important to know only that it rained and not the amount.

It is important to take daily readings of rainfall. In these cases, report 1 for the number of days rain has accumulated. If it is not possible to read the gauge for several days, you must report the number of days since the gauge was last read or emptied. You must report the number of days even if the reading is zero. Thus, for example, if you emptied the rain gauge on Friday, missed reading the rain gauge on Saturday and Sunday, but read it on Monday, enter 3 days for Monday along with the actual reading.

Solid Precipitation Protocol

Purpose

To measure solid precipitation at the Atmosphere Study Site

Overview

Climate studies and Earth System studies require accurate, long term solid precipitation measurements.

Time

5 minutes

Level

All

Frequency

Daily within one hour of local solar noon.

Key Concepts

Change of state
Heat capacity
Density of snow

Skills

Reading a scale
Recording data

Materials and Tools

Meter stick (If your snow tends to be deeper than one meter, you will need a longer measuring pole.)
Snowboard

Prerequisites

None

Background

A snowboard is a thin, flat surface that rests on top of earlier layers of snow. New snow falls on top of it and can be measured with the measuring stick. The board may be made of thin plywood (1 cm or 3/8"). The board should be at least 40 cm by 40 cm in size so that more than one snow-depth measurement can be made. Mark the location of the snowboard so that it can be easily located after it has been covered by a new snowfall.

In most cases a meter stick will be adequate to use as the "measuring pole". However, in regions where the 24 hour snowfall and/or snow accumulated on the ground throughout the winter exceeds 1 meter, a longer measuring stick will be necessary. In these cases, a measuring pole can be made by taking a straight piece of wood and carefully marking off lengths using a ruler and a permanent marker. The pole may be permanently installed as it is often difficult to push a pole vertically through more than 1 meter of snow.

How to Measure Solid Precipitation

1. For your first snowfall, insert the measuring stick vertically into the snow until it rests on the ground's surface. *Be careful not to mistake an ice layer or crusted snow for the ground.* Repeat the measurement in several places where the snow is least affected by drifting. If there is no new snow, enter 0. If the measured depth is between 0 and 0.5 millimeter, enter the letter "T" (for trace).
2. Place the snowboard on top of existing snow and push gently into the snow so that its surface is flush with the snow's surface. Place a flag or other marker nearby to help you locate the snowboard after the next snowfall.
3. After a new snow has fallen on earlier snow, gently insert the measuring stick into the snow until it touches the snowboard. Take several measurements at different spots on the snowboard and average these measurements. This will be

your depth of new snow on the snowboard.

4. Measure total depth of snow on the ground at the same time as the daily accumulation. The procedure is the same as for measuring the first snowfall: insert the measuring stick vertically into the snow in several places (not in the area of the snowboard) and take the average of the depth readings.

Determining Liquid-Water Content of Daily Solid Precipitation

Not all snowfalls are alike. Some are light and fluffy while others are wet and heavy. The daily liquid equivalent of solid precipitation is determined by melting a sample of snow and measuring the volume of the water

For this measurement, a collection container is necessary. When outside temperatures are below freezing, the plastic rain gauges used for liquid precipitation measurements may crack and break, so they should be brought indoors. However, the large, overflow cylinder of the rain gauge makes an ideal container to collect snow to determine liquid-water content.

1. Once you have measured the depth of daily snowfall on the snowboard, take the large cylinder from the rain gauge and invert it on the snowboard, pushing the cylinder down carefully so that it touches the board's surface. If the depth of snow is greater than the depth of the overflow cylinder, you may compact the snow in the cylinder. In doing this, be careful that you are not pushing snow out of the path of the cylinder. If the snow is too deep, you may not be able to compact the snow into the cylinder as a single sample. Depending on the size of your snowboard and the depth of snowfall, there are at least two ways to get that circle of snow into your cylinder.

   Method A

   If your snowboard is not large or heavy, hold the cylinder against the board and invert both snowboard and the cylinder. This will cause the snow outside the cylinder to fall off the board, so be sure you've made your depth measurement first. The snow trapped in the cylinder can now be taken indoors.

   Method B

   If your snowboard is too big or heavy to turn over easily or if the snow column, even when compacted, will not fit into the cylinder, you will have to transfer the snow into the cylinder or other container by hand. Carefully lift the cylinder off of the board and you should have a nice circle of snow in the shape of the cylinder. Carefully scoop the snow from within this circle into your cylinder or other container.

2. Once the snow is inside the cylinder or other container, bring it indoors and allow it to melt. Place a cover over the container to prevent evaporation.
3. When the snow has melted, carefully pour the water into the measuring tube of the rain gauge and read the depth of water in the same way you read the rainfall.

It is possible that an overnight snowfall may melt before the daily precipitation measurement is made. If you have left your overflow cylinder outside, you can still report the liquid water equivalent of your snowfall. Enter "M" for Daily depth of new snow and 0.0 mm for Total depth of snow on the ground. In cases like these a message can be entered under comments noting that snow fell and melted or blew away. If you have measured the depth of snow before it melted, this could also be reported under comments, along with the time you made the measurement. Remember that measurements reported in the regular section of the data sheet should be the measurements taken within one hour of local solar noon.

Setting Up for the Next Measurement

After you have completed your snow observation, clean the snowboard and again place it flush on the snow's surface

Data Submission

Report the following information to the GLOBE Student Data Server:

- Date and time of data collection (in Universal Time)
- Total depth of snow on the ground (mm)
- Daily depth of new snow (mm)
- Number of days snow has accumulated on the snowboard
- The depth of water from the melted snow on the snowboard (mm).

Note: If snow has fallen but, for some reason, measurements cannot be taken (for example, the snowboard has blown away or someone accidentally cleared it before a measurement could be taken) then enter the letter "M" (for missing). The total snow depth can still be reported.

On days when the snowfall is so small that a depth cannot be read, enter the letter "T" (for "trace") for the daily snowfall.

It is important to take daily readings of snowfall, but if this is not possible, then, if the snowfall has not been measured for several days (for example over the weekend), enter the number of days since the snowboard was last cleared along with the amount of snowfall. This indicates that the measured amount was collected over more than a 24-hour period. Thus, for example, if you missed reading the snowboard on Saturday and Sunday but read it on Monday, you would enter 3 days for Monday along with the actual reading.

Precipitation pH Protocol

Purpose

To measure pH of rain and snow

Overview

The pH of precipitation affects the region on which it falls. *Acidic precipitation* can affect vegetation, buildings, statues, and change the pH of water in surface water bodies or in the soil.

Time

5 minutes for actual measurements

5 minutes to calibrate the pH pen or pH meter

Level

All

Frequency

For rainfall: Whenever you have accumulated at least 2 mm of rainfall in your rain gauge

For snowfall: Whenever there has been enough new snowfall such that you can collect snow which has not been in DIRECT contact with the ground or with your snowboard and this snow, when melted, produces at least 20 ml of liquid.

Key Concepts

Factors affecting the pH of precipitation

Skills

Using pH measuring equipment

Recording data

Materials and Tools

pH measuring equipment (pH indicator paper for beginning; pH pen for intermediate; pH meter for advanced level students; plus necessary calibration materials)

Rain gauge

Snowboard

100 mL beaker

Preparation

Read and be familiar with *Hydrology Investigation pH Protocol*. If your students are at the intermediate or advanced level, make sure your pH pen or pH meter has been conditioned and calibrated according to the instructions in that protocol.

Prerequisites

None. Although the equipment used in this protocol is the same as that in *Hydrology Investigation pH Protocol*, you do not need to be making pH measurements at a water sample site in order to make precipitation pH measurements.

Beginning Students: pH Indicator Paper

It is quickest and easiest to take a clean, dry beaker and pH paper with you to your rain gauge site and make the pH measurement immediately after reading and recording the rainfall amount.

1. Use a clean, dry 100 mL beaker.
2. After reading and recording the amount of rainfall in your rain gauge, if there has been at least 2 mm of accumulated rainfall, pour the rain water into the beaker. If there has been a large amount of rainfall, you need only fill the beaker about half full with the rain water.
3. Dip one strip of pH indicator paper into the rain water in the beaker and hold it there for about 20 seconds. Make sure all of the colored segments of the paper are immersed in the rain water.

4. Remove the paper from the water and compare the resultant color segments with the chart on the pH indicator paper box. Try to find a sequence where all color segments on the paper match all segments on one of the stripes on the box.
5. If the reading is unclear, the paper may need more time to fully react. Place the paper back in the rain water in the beaker for an additional 20 seconds, then repeat steps 4 and 5. Repeat until you are satisfied that the reading is accurate. If, after 2 minutes, the reading is still unclear, start all over with a new strip of paper. If the test fails a second time, indicate this on your Atmospheric Investigation Data Work Sheet.
6. If you are satisfied that you have a good pH reading, record the pH value on the Atmosphere Investigation Data Work Sheet.
7. If you have had enough rainfall, repeat Steps 2 through 5 as a quality control check.
8. Report your measured pH to the GLOBE Student Data Server
9. Regardless of whether or not it has rained, your rain gauge must be thoroughly scrubbed using distilled water and dried at least once per week. Any foreign material in your rain gauge can affect your pH reading. DO NOT USE SOAP OR DETERGENTS IN YOUR RAIN GAUGE AS RESIDUES CAN AFFECT YOUR pH READING!

Intermediate/Advanced: pH pen/ pH meter

Step 1: Conditioning and calibration of the pH pen or meter

Follow the instructions in *Hydrology Investigation pH Protocol* for conditioning and calibration of your instrument.

Step 2: Measuring the pH of the collected rainfall

Take your calibrated pH pen or meter and a clean, dry beaker with you to your rain gauge site, and make your pH reading immediately after reading the rainfall amount.

1. Prior to leaving the classroom, remove the cap and rinse the electrode and the surrounding area of your pH pen or meter with distilled water. Blot the area dry with a soft tissue.
2. Obtain a clean, dry 100 mL or larger beaker, and take it, as well as your pH pen or meter, with you to the rain gauge site.
3. At the rain gauge, read and record the amount of rainfall.
4. If there is at least 2 mm of rainfall in your gauge, pour the rain water into the beaker. If there has been a large amount of rainfall, you need only fill the beaker about half full with rain water.
5. Immerse the electrode of your pH pen or meter in the water in the beaker. Be sure that the entire electrode is immersed but avoid immersing it any further than necessary. If you do not have enough rain water to completely immerse the electrode, do not make a rainfall pH measurement.
6. Stir the rain water once with the pH pen or meter and then let the display value stabilize.
7. Once the display value is stable, read the pH value and record it on the Atmosphere Investigation Data Work Sheet.
8. If you have enough rainfall left in your gauge, repeat steps 4 through 7 for another sample as a quality control check. The two pH values should agree to within

0.2 (which is the accuracy of this technique). If they do not, make a third measurement with a new sample of rain water (if there is sufficient water in the gauge). If there is not sufficient rain water for a third measurement, do not report a precipitation pH value to the GLOBE Student Data Server, and recheck the calibration of your pen or meter before your next measurement.

9. If you only have enough rain water to make a single pH measurement, report this pH value to the GLOBE Data Server.
10. If there is enough rain water for two separate measurements to be made, and these measurements agree to within 0.2, report the average pH value to the GLOBE Data Server.
11. If you had enough rain water to make three or more pH measurements, take the average of the pH values measured. If all recorded values are within 0.2 of this average, report the average value to the Student Data Server. If there is only one outlier (a value that is far different from the rest), discard that value and calculate the average of the other values. If they are all now within 0.2 of this new average, report this new average to the Data Server, with the notation that 3 or more measurements were made (even if all three measurements were not included in the average pH value reported). If there is a wide scatter in pH readings, do not report a value to the Data Server. Check the calibration of your instrument and discuss procedure and potential sources of error.
12. Rinse the pH pen or meter with distilled water, blot it dry with soft tissue, replace the cap on the probe, and turn off the instrument.
13. Regardless of whether or not it has rained, your rain gauge must be thoroughly scrubbed using distilled water and completely dried at least once per week.

Any foreign material in your rain gauge can affect your pH reading. DO NOT USE SOAP OR DETERGENTS IN YOUR RAIN GAUGE AS RESIDUES CAN AFFECT YOUR pH READING!

Collection of Snow for pH Measurement

Although you may be measuring the depth of snowfall and its liquid water equivalent, you need to be a bit more careful in collecting snow to make your pH measurement. The snowboard that you use for snow depth (see *Solid Precipitation Protocol*) may sit out for quite a while before there is actually any snow on it. Thus, material like leaves or soil may collect on the board. When you take a "core" of snow from the snowboard to determine liquid water equivalent, the snow at the bottom (that is in direct contact with the board) may have reacted with the material on the board (or the board itself). What we really want to measure is the pH of the snow itself. Therefore, if you are going to measure snow pH, you will need to gather a second sample of snow in addition to the sample gathered to determine liquid water equivalent.

For the pH snow sample, you want to also take a *core* of snow from the snowboard. However, you don't want to go all the way down to the board itself if you can help it. The reason you want to take a core rather than just scooping snow off the top is because the pH of the snow may change the longer the snow falls. What we want to get is the average pH of the snowfall. Thus, we want a core of snow, but stopping just short of getting all the way down to the snowboard itself. In order to obtain enough snow to produce at least 20 mL of water once the snow melts, you may collect several cores from other locations on your snowboard.

Any clean, dry, deep container (glass or plastic) can be used to collect the snow sample for the pH measurement. Once you have collected the snow, take the container inside and cover it. Let the snow melt at room temperature.

When the snow has melted you are ready to make your pH measurement as described in the sections above using the melted snow instead of the rain water and taking the measurement in the classroom instead of at the Atmosphere Study Site.

Maximum, Minimum, and Current Temperatures Protocol

Purpose

To measure air temperature at the Atmosphere Study Site

Overview

Climate studies and Earth systems studies require accurate, long-term air temperature measurements.

Time

5 minutes

Level

All

Frequency

Daily within one hour of local solar noon

Key Concepts

Heat
Temperature
Convection
Conduction
Radiation

Skills

Using a thermometer
Recording data
Reading a scale

Materials and Tools

One maximum/minimum thermometer
An instrument shelter
A second thermometer for calibrating the maximum/minimum thermometer
Atmosphere Investigation Data Work Sheet

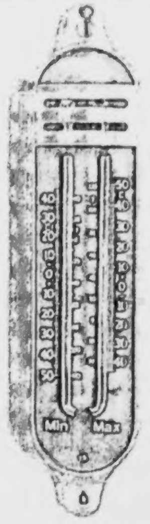
Prerequisites

None

Background

The maximum/minimum thermometer is a U-shaped tube with two indices that indicate the maximum and minimum temperatures. See Figure ATM-P-3. On the maximum side, the temperature scale is such that temperature increases as you go from bottom to top (as with household thermometers). On the minimum side, the scale shows temperature decreasing as you go from bottom to top. Thus, as the temperature increases, the indicator at the top of the mercury column on the maximum side of the thermometer is pushed upward. When the temperature drops, the indicator remains in place to indicate the maximum temperature. Similarly, as the temperature decreases, the indicator above the mercury column on the minimum side is pushed upward. When the temperature again increases, this indicator remains in place to indicate the minimum temperature.

Figure ATM-P-3: Maximum/Minimum Thermometer



Note: The mercury pushes the bottom of indicators until the maximum or minimum temperature is reached. Therefore, students read the maximum and minimum at the bottoms of the indicators.

If your thermometer has a Fahrenheit scale, paint over it so that students will not read it by mistake. Note that the thermometer shown in Figure AT M-P-3 has a Fahrenheit scale which should be painted black.

Before using your maximum/minimum thermometer, make sure that the column of mercury is continuous because it sometimes separates into segments during shipping. If there are gaps in the mercury column, grasp the thermometer by the case, making sure the thermometer is in an upright position, and shake the case until the mercury forms a continuous column. Do not press against the stem of the thermometer as this could cause breakage. You may need to tap the bottom of the thermometer against the palm of your hand as well.

Calibration

Your maximum/minimum thermometer should be calibrated upon installation and again every six months after installation. (More frequent calibration may be required if you find the current temperature does not read the same on both scales or, if at some point, the mercury column becomes discontinuous and needs to be fixed. See above.)

To calibrate the maximum/minimum thermometer, you should compare it with a calibration thermometer. The calibration thermometer will be a typical, liquid-filled, single-tube thermometer that can record temperatures at least as low as -5 °C. The calibration thermometer itself must first be tested for accuracy by placing it in an ice-water bath.

1. Prepare a mixture of one part liquid water to one part crushed ice.
2. Allow the ice-water bath to sit for 10 to 15 minutes so it reaches its lowest temperature.
3. The bulb of your calibration thermometer should then be placed in the bath. Gently move the thermometer around in the ice-water bath so that it will be thoroughly cooled. The thermometer should read between 0.0 and 0.5 °C. If it does not, use another thermometer.
4. Once you are confident of the accuracy of your calibration thermometer, hang it by a hook in the instrument shelter. See instructions below for placing the maximum/minimum thermometer.
5. After 24 hours, compare the temperatures on both thermometers. If they differ, the maximum/minimum thermometer should be calibrated to the temperature of the calibration thermometer. Adjust the temperature scales on both sides of the thermometer by loosening the small screw located in the back of the thermometer. Once this screw is loosened, the scales can slide up or down independently of each other.

Placing the Maximum/Minimum Thermometer

Mount the maximum/minimum thermometer in the instrument shelter so that there is air flow all around the thermometer case. The thermometer should be attached to blocks on the rear wall of the shelter so that no part of it touches the walls, floor, or ceiling of the shelter. The thermometer must be 1.5 meters above the ground or 0.6 meters above the average maximum snow depth, whichever is higher. The shelter protects the thermometer from radiation from the sun, sky, ground, and surrounding objects, but allows air to flow through so the air temperature inside the shelter is the same as the air temperature outside the shelter.

The instrument shelter should be mounted on a post that is secured in the ground as firmly as possible so as to eliminate vibrations caused by strong winds. Vibrations can displace the indicators on the maximum/minimum thermometer and thus cause erroneous readings. The shelter's door should face north in the Northern Hemisphere and south in the Southern Hemisphere to reduce exposure of the thermometer to direct sunlight when the door is open for the daily measurement.

The instrument shelter should conform to the specifications given in the *GLOBE Instrument List* in the *Toolkit* section of this guide. It may be constructed using the plan in the Toolkit. It should be painted white both inside and outside. The lock is to prevent tampering with the instruments. Mounting blocks should be installed on the interior to ensure that the maximum/minimum thermometer does not touch the back wall. The door is hinged on the right side (this is not shown in the diagram. The parts should be screwed together. The plans are specified in metric units. See the Toolkit for detailed shelter construction plans.

Once the shelter is in use, occasionally dust its inside with a dry cloth.

How to Measure Air Temperature

1. Assign a team of students to read the thermometer daily within one hour of local solar noon. They should stand as far from the thermometers as possible to prevent body heat from changing the temperature reading. This is very important in cold weather. Do not touch or breathe on the temperature-sensing parts of the thermometer as this, too, may affect the reading.
2. Students should read the current daily temperature at the top of the column of mercury on either the maximum or minimum sides of the u-tube thermometer. Make sure that their eyes are level with the top of the mercury column. Otherwise the reading will be too high or too low.
3. Take the maximum and minimum readings at the base of the indicators. Make sure the eyes of the observer are level with the base of the indicator.
4. Once the maximum, minimum, and current temperatures are read, students should reset the indicators. This is done by using a small magnet to drag the indicators down until they are on top of the mercury column. To avoid losing the magnet, attach it either to the shelter or to the thermometer with a piece of string.

When a temperature observation is missed, reset the thermometer at the next observation and record only the current temperature at that time. Since more than 24 hours have elapsed between readings, we have no way of knowing on which day the maximum and minimum temperatures occurred.

Data Submission

Report the following data to the GLOBE Student Data Server:

Date and time of the data collection in Universal Time
Current air temperature
Maximum daily air temperature
Minimum daily air temperature

Learning Activities

Observing, Describing, and Identifying Clouds

Students will begin to learn cloud types and their names.

Estimating Cloud Cover: A Simulation

Students will practice estimating how much of the sky is covered by clouds.

Studying the Instrument Shelter

Working in teams, students will explore how the placement of the instrument shelter and its characteristics can influence measurements.

Building a Thermometer

Students will construct simple thermometers to understand how and why liquid-in-glass thermometers work.

Land, Water, and Air

This hands-on activity will show students the different cooling and heating rates between land and water, which accounts for much weather

Cloud Watch

Students will monitor clouds and weather to begin to understand the connections between the two.

Observing, Describing, and Identifying Clouds

Purpose

To enable students to observe clouds, describe them in a common vocabulary, and compare their descriptions with the official cloud names

Overview

Students observe and sketch clouds, describing their forms. They will initially generate descriptions of a personal nature and then move toward building a more scientific vocabulary. They correlate their descriptions with the standard classifications using the ten cloud types identified for GLOBE. Each student develops a personal cloud booklet to be used in conjunction with the GLOBE Cloud Chart.

Time

Two class periods. May be repeated on days when different kinds of clouds are present

Level

All

Key Concepts

Clouds are identified by their shape, altitude, and precipitation characteristics.

Skills

Observing and *describing* the appearance of clouds

Identifying the ten major cloud types

Estimating cloud height

Recording and *organizing* cloud data in the GLOBE Science Notebook

Materials and Tools

GLOBE Cloud Chart

Observing Cloud Type Sheets (in the Appendix)

GLOBE Science Notebooks

Reference books containing cloud images

Still or video camera to photograph clouds (optional)

Preparation

Obtain cloud reference books and mark the appropriate pages.

Prerequisites

None

Background

Accurate weather forecasting starts with careful and consistent observations. The human eye represents one of the best (and cheapest) weather instruments. Much of what we know about the weather is a result of direct human observation conducted over thousands of years. Although being able to identify clouds is useful in itself, observing clouds on a regular basis and keeping track of the weather associated with certain kinds of clouds will show students the connection between cloud types and weather. Recognizing cloud types can help you predict the kind of weather to expect in the near future. We do not describe those connections here, but there are numerous weather books that can help you and your students make them. Inviting a local meteorologist to visit your class and talk with the students is a sure way to stimulate interest in the relationship between clouds and weather patterns.

In this activity, we ask students to look carefully at clouds, sketch them, and describe them in their own words *before* using the official names. The activity can be repeated on different days when different kinds of clouds are present. In fact, if you can be spontaneous, it would be nice to take a break and do some outdoor "cloud work" whenever a new kind of cloud appears in the sky. Over time, students can build up a considerable familiarity with cloud types. And, if you cannot always take the students outside when some interesting clouds appear, perhaps you can observe through a window.

Students Develop a Personal Cloud Booklet

Students should develop, either in their GLOBE Science Notebooks or in separate cloud booklets, an individual, personal set of notes on clouds and cloud types. They should devote one page of their GLOBE Science Notebooks to each individual cloud type they identify. They can include not only their own observations and descriptions but also photographs of clouds that they take or that they clip from other sources. On any given day students may observe several kinds of clouds in the sky at the same time. If several types of clouds are present, they should record each of the types on a separate page of their GLOBE Science Notebooks.

Identifying and Classifying Clouds

The GLOBE protocol asks you to identify ten common types of clouds. The names used for the clouds are based on **three factors** their **shape**, the **altitude** at which they occur, and whether they are **producing precipitation.**

1. Clouds come in three basic shapes:
   cumulus clouds (heaped and puffy)
   stratus clouds (layered)
   cirrus clouds (wispy)
2. Clouds occur in three altitude ranges (specifically, the altitude of the cloud base):
   High clouds (above 6,000 m), designated by "cirrus or cirro-"
   - Cirrus
   - Cirrocumulus
   - Cirrostratus

   Middle clouds (2,000 - 6,000 m), designated by "alto-"
   - Altocumulus
   - Altostratus

   Low clouds (below 2,000 m), no prefix
   - Stratus
   - Nimbostratus
   - Cumulus
   - Stratocumulus
   - Cumulonimbus

Note: While both cumulus and cumulonimbus clouds may have their bases starting below 2,000 m, they often grow thick enough to extend into the middle or even high range. Thus, they are often referred to as "clouds of vertical development." Only high clouds are wispy and so the term cirrus has become synonymous with wispy as well as referring to high clouds.

3. Clouds whose names incorporate the word "nimbus" or the prefix "nimbo-" are clouds from which **precipitation** is falling.

Cloud Identification Tips

Several things are useful to know in identifying and naming clouds according to the official classifications:

Clouds that are wispy and high in the sky are always cirrus of one type or another. If the cirrus clouds contain waves or puffs, then they are cirrocumulus. If they form continuous layers that seem to cover the sky high up, they are cirrostratus.

Clouds at middle altitudes are designated by the prefix "alto-." If in layers, they are altostratus; if in heaps and puffy, they are altocumulus.

Clouds that form at low altitudes (below 2,000 m) are either of the cumulus or stratus family. Clouds in the cumulus family are puffy and heaped. Clouds in the stratus family form in layers or sheets that cover broad expanses of sky.

Low clouds that are dark, threatening and *actually producing rain* receive the designation "nimbus." Nimbostratus clouds cover the entire sky with broad sheets and produce steady rain. Nimbostratus clouds are larger horizontally than vertically. The rainfall associated with nimbostratus typically is low to moderate in intensity, but falls over a large area for an extended period of time. Cumulonimbus have dark bases and puffy tops, often anvil-shaped, and are sometimes called "thunderheads." They tend to produce heavy precipitation, typically accompanied by lightning and thunder.

Using Photography

It should not be hard to find photographs of clouds in books, charts, and magazines. However, the students will enjoy taking their own photographs of clouds. Introduce this as an activity after they have sketched and described clouds in their own words. Videophotography of clouds in motion also presents a new perspective on cloud formation and behavior, particularly if you can use a tripod and time-lapse photography.

Part 1: Describing Clouds In Your Own Words

What To Do and How To Do It

1. Organize the students into two-person teams. Send them outside with their GLOBE Science Notebooks to an open location to observe the clouds. Each student should draw a detailed sketch of the clouds in the sky. If there are several different kinds of clouds present, then they should sketch each specific kind on a separate page of their notebooks.
2. Each student should record the date and time of day and describe the appearance of the clouds next to the sketch. They should use as many words as necessary to describe the appearance of the clouds. Emphasize that there are no right or wrong answers and that they should use whatever words seem appropriate to them. Some possible student responses:

   Size: small, large, heavy, light, dense, thick

   Shape: fluffy, stringy, cottony, lumpy, torn, smooth, patchy, sheets, ragged, looks like a...

   Color: gray, black, white, silvery, milky

   Description: thunderclouds, menacing, threatening, gloomy, enveloping, beautiful, streaked, foggy, bubbly, scattered, moving, swirling
3. Upon returning to the class, pairs should join together to share descriptions. Ask each group of four to compile a "group list" of all the words they used to describe each cloud type they observed. They should select the words they think are the best ones for describing the clouds they saw.
4. Using the GLOBE Cloud Chart, they should match their sketches with one of the photographs and record the scientific name of the cloud type next to their sketch.

Part 2: Comparing Your Descriptions to the Official Descriptions

What To Do and How To Do It

1. (You may choose to postpone this discussion until the class has accumulated descriptions of several different kinds of clouds.)

   Initiate a class discussion. Ask one four-person group to draw its cloud sketch on the board and record the words their group used to describe the cloud. If several different clouds have been observed, have a different group do each type. Ask other groups to contribute additional words they used to describe these clouds.

   Ask the students to group the words they used into clusters that seem to go together. Ask them to name the specific features of the clouds (such as size, shape, color, altitude, or other features) to which these clusters refer. Do these clusters represent the main cloud features to which they think an observer should pay attention? Are there any cloud features that have not been included? What would they say is the basis of their system, that is, what features of clouds does it pay attention to?
2. Ask the students to indicate the "official" names for the clouds pictured on the board. Explain that the official system used to classify clouds relies upon three features of clouds: shape, altitude, and precipitation. Compare the official system to the classification system they developed on their own. What cloud features does each include and omit?

Ask students which of their words they would use to describe each of these cloud families:

- stratus clouds
- cumulus clouds
- cirrus clouds
- nimbus clouds

3. Repeat the observation, sketching, and description of different cloud types on subsequent days as new clouds appear in your sky. Have students develop a separate page of their GLOBE Science Notebooks for each new cloud type they observe. Have them record both the official name of the cloud and their own preferred descriptions of it. Continue to discuss the basis for the official classification system.

Adaptations for Younger and Older Students

Younger students can describe clouds in terms of their basic family type: cirrus, cumulus, and stratus. They can also describe the height of the clouds: low, medium, or high; their shape: large or small; and their color: white, gray, or black.

Older students can correlate cloud types with the appearance of certain types of weather. See the *Cloud Watch Learning Activity*. Students also can pay attention to the sequence of cloud types over the course of several days and can investigate the factors that cause clouds to form.

This activity can present interesting possibilities for collaboration with an art teacher or a literature teacher, each of whom can contribute a different, perhaps nonscientific, perspective on the description of clouds.

Further Investigations

Examine the correlation between wind and clouds. Chart the wind direction and speed for each observable cloud type.

Explain the connection between the hydrologic cycle and atmospheric conditions.

Satellite and shuttle photos allow observations of the dynamics of our atmosphere and the examination of large-scale phenomena that are not possible from land. Use space-based imagery to predict weather or to track storms. Consider the merits and disadvantages of space images versus local meteorological information and data.

Track storms and clouds from a distance to aid in understanding local weather conditions. Use binoculars to study clouds and their formations from a distance. Use local maps to help identify the distance of landmarks and the speed at which clouds are moving.

Create cloud games to practice identification skills and concepts:

Cloud Game #1 Have each student create a set of 3" x 5" index cards that includes names of the ten cloud types. A second set of cards includes illustrations of each of the ten types. Pairs of students combine cards, turning them face down. Partners alternate turning over two cards at a time, attempting to locate a match. A successful match results in another turn. Play continues until all cards have been matched. The winner is the partner with the most matched pairs.

Cloud Game #2 Groups of students can generate questions about clouds: appearance, shape, altitude, and percentage of dominant cover. On a 3" x 5" index card write the statement as an answer. For example: "Scattered Clouds" is the answer to the question, "What is the cloud cover when between a tenth and a half of the sky is covered with clouds?" Divide the class into teams to play. Players respond to the answer cards in the form of a question (see above).

Estimating Cloud Cover: A Simulation

Purpose

To enable students to understand the difficulties of visually estimating the percentage of cloud cover, to practice estimating cloud cover using paper simulations, and to evaluate the accuracy of their estimates

Overview

Working in pairs or small groups, students will use construction paper to simulate cloud cover. They will estimate the percentage of cloud cover and assign a cloud cover classification.

Time

One class period

Level

Intermediate and Advanced

Key Concepts

Using a simulation to explore the accuracy of observations

Skills

Estimating simulated cloud cover
Communicating mathematically
Collecting and *recording* data
Organizing data in tables

Materials and Tools

GLOBE Science Notebooks
Sheets of colored construction paper, one blue and one white per student
Glue stick or tape

Prerequisites

Familiarity with the cloud cover classification system

Familiarity with fractions and percentages

Background

Even experienced observers have difficulty estimating cloud cover. This seems to derive, in part, from our tendency to underestimate the open space between objects in comparison to the space occupied by the objects themselves, in this case the clouds. Students have an opportunity to experience this perceptual bias themselves, to reflect on its consequences for their scientific work, and to devise strategies to improve their ability to estimate cloud cover.

What To Do and How To Do It

Review the cloud-cover protocol with the students. Explain that they will simulate cloud cover using construction paper and try to estimate the amount of cloud cover represented by white scraps of paper. Demonstrate the procedures covered in steps 3 - 6 below so that students understand how to proceed.

1. Provide each student with the necessary materials:
   - one sheet of light blue construction paper
   - one sheet of white construction paper divided into 10 equal segments
   - GLOBE Science Notebooks
   - glue stick or tape.
2. Organize students into pairs.
3. Tell each student pair to choose a percentage of cloud cover that they wish to represent. They must choose a multiple of 10% (i.e. 20%, 30%, 60%, etc. not 5% or 95%). They should not reveal the percentage they have chosen to anyone else.

4. Working separately, each pair should cut their white paper so that it represents the percentage of cloud cover they have chosen. For example, if they have chosen 30%, they should cut out 30% of their white piece of paper and recycle the remaining 70%.
5. Students then tear their white paper into irregular shapes to represent clouds.
6. The students paste or tape the smaller cloud pieces onto the blue paper, thus representing the cloud cover.
7. Students take turns visiting each others' simulations and estimating the percentage of cloud cover. They also classify each simulation as "clear, scattered, broken, or overcast." They record their estimates in their notebooks, using a table similar to that shown in Figure ATM-L-1.

You may choose to have all students visit all the simulations, or divide the class in some way so that students visit only some of the simulations.

8. When students complete their estimates of cloud cover, create a table on the board to compare the estimates with the actual percentages. See Figure ATM-L-2.
9. Create a second table that compares correct classifications with incorrect classifications. See Figure ATM-L-3.
10. Discuss with the class the accuracy of their estimates.

Which were more accurate—the percentage estimates or the classifications?
Where did the greatest errors occur?
Can students come up with a quantitative measure of their collective accuracy?
Does the class have a tendency to overestimate or underestimate cloud cover?
What factors influenced the accuracy of the estimates (e.g. size of the clouds, clustering of the clouds in one part of the sky, the percentage of sky that was covered)?
Do students feel that making these estimates is something one has a knack for, or is it something that can be learned?
Where else might such spatial estimation skills be valuable?
Which cloud classifications were the easiest and most difficult to identify?
What strategies enabled students to succeed?

Figure ATM-L-1

Name	Estimated percent	Classification
Jon & Alice	40%	scattered
Juan & Jose	70%	broken

Figure ATM-L-2

Name	Actual %	Underestimates	Correct estimates	Overestimates
Jon & Alice	50	4	5	12

Figure ATM-L-3

Name	Correct classification	Classified too little cover	Classified correctly	Classified too much cover
Jon & Alice	Scattered	4	9	8

What strategies might produce more accurate classifications?

Adaptations for Younger and Older Students

Younger students may need instruction regarding the identification of fractional *equivalents* and converting simple fractions to percents.

Older students can produce and videotape daily forecasts simulating a local news or weather channel. The broadcast format can include clips of dominant cloud types, percentage of cloud cover and visibility reports.

Studying The Instrument Shelter

Purpose

To discover why the instrument shelter is built the way it is

Overview

Students will explore some of the characteristics of the instrument shelter and its placement. The main part of this activity will be to construct shelters that have varying properties and investigate the effect of these properties on the measured temperature. Students should be asked to predict what they believe will happen for each of the different shelter designs.

Time

One class period for discussion of the shelter and design of an experiment. Two to three additional class periods to experiment with model shelters.

Level

All

Key Concepts

Heat transfer through radiation, conduction, and convection

Skills

Hypothesizing and *predicting*
Designing experiments
Collecting data
Organizing and *analyzing* data
Communicating experimental results orally and in writing

Materials and Tools

At least two cardboard instrument shelters (depending on the number of properties to be explored and the availability of materials). These could be in the form of ready-made boxes such as an oatmeal container or a shoe box.

It is best if all the experimental shelters are the same, so that size and shape do not become factors. If only sheets of cardboard are available, then shelters can be constructed from some agreed-upon plan.

For every property to be explored, at least two cardboard shelters will be needed.

Depending on the number of characteristics to be investigated, the following materials may be needed:

White paint and black paint (to investigate color)

Two paint brushes (if paint is used)

Heavy-duty scissors (necessary if the shelters must be made from sheets of cardboard and also to investigate the purpose of slits in the shelter)

Paper (to compare the effect of having shelters made of different materials)

Two or more thermometers per student group (depending on the number of properties to be tested at the same time)

String

One or more wooden posts, strong enough to be placed in the ground and hold the instrument shelter (shelters can be nailed onto the posts)

Nails (to attach shelters to the posts, if necessary)

Hammer

Meter stick

The actual GLOBE instrument shelter

If the actual shelter is not available, then the students should have the picture and physical description of it given in the *Toolkit*.

Preparation

Gather those materials needed to construct the shelters. Students could bring oatmeal boxes (round) or shoe boxes from home.

Prerequisites

An assembled instrument shelter

Background

While it may seem that air temperature should be an easy enough measurement to make, it is not necessarily easy for many people around the world to make precisely the same measurements so they can be compared with each other. In order to really understand the temperature being measured, we all need to measure the same thing. Factors such as wind, direct sunlight, and moisture can affect a thermometer and so we must protect these instruments by placing them in a shelter that is built to a specific set of characteristics. In addition, where this shelter is placed and how the thermometer is placed inside of it are of critical importance.

We need to be certain that the temperature differences reported from various areas are due to real differences in the air temperature and do not just reflect the fact that one person put a thermometer in a shelter in the middle of a grassy field and someone else put a thermometer on the window in direct sunlight.

What To Do and How To Do It

Day One

1. You should start the discussion by asking students to identify the major characteristics of the GLOBE shelter that could influence the temperature inside it. These would include:
   - The color of the shelter
   - The slits in the shelter
   - The materials of which the shelter is made

   The discussion should turn to why the students think these characteristics are important.
2. The discussion of the physical characteristics of the shelter should be followed by a discussion of the placement of the shelter and the thermometer inside the shelter. Questions to ask are:
   - Why should the shelter be located away from buildings and trees?
   - Why should it be placed over a natural surface, such as grass?
   - Why should it be placed 1.5 meters above the ground?
   - Why should the shelter be oriented with the door facing north in the northern hemisphere and south in the southern hemisphere?
   - Why is the thermometer not supposed to touch the shelter?

Students should predict the effect that each of the above parameters has on the measurement of temperature. Then it will be time to test their predictions.

Day One/Day Two (depending on how long the discussions take)

1. Students should be divided into teams. The number of teams will be determined by the number of properties to be investigated, the availability of materials, and the number of students. Up to eight teams could be formed to explore the eight basic parameters discussed above.
2. Each team should construct two shelters. This is a simple task if students use ready-made boxes such as oatmeal or shoe boxes, but will be more complicated if they must make shelters from sheets of cardboard.

   If shelters are made from sheets of cardboard, the actual design of the shelter (whether it is a cylinder, like an oatmeal box, or a rectangle, like a shoebox) is not as important as the fact that all shelters should be as close to the same design and size as possible.
3. Each team chooses or is assigned a property to explore. For those investigating the physical properties of the shelter, further work on the shelter will be necessary. The following are possible alterations to shelters to study the properties:
   - Paint one shelter white and one black
   - Make one shelter with slits and one without (paint both white)
   - If you are using ready-made boxes, then use white paper to construct a shelter of similar shape and size to the cardboard one. Paint the cardboard shelter white.

4. All shelters should be mounted on posts (unless a team is investigating the effect of the height of the shelter above the ground). For most teams, the posts do not need to be more that a meter high. The team investigating shelter height above the ground should leave one shelter unmounted and mount one on a post approximately 1.5 meters high.
5. Each team should be given two thermometers. Prior to placing the thermometers in their shelters, the students must make sure that the thermometers read the same temperature while indoors. If they do not, then they should be calibrated following the instructions in the Atmosphere protocols. If a thermometer does not read within 0.5 °C of 0 °C while in an ice water bath, that thermometer should not be used. Thermometers should not be placed in the shelters until the students are ready to take their shelters outside.

Day Three/Day Four

1. Choose a day that is mostly sunny and, ideally, slightly breezy. You do not want an overcast, rainy, or snowy day.
2. Each team should record the starting temperature of their thermometers. (Again, these should be the same.)
3. The thermometers should be placed in the shelters in such a way that they do not touch the cardboard (or paper) surface (unless, of course, the group is exploring the effect of the thermometer touching the shelter wall). If ready-made cardboard boxes are used, the thermometer can be hung by a string from the top of the shelter.
4. Each team takes its two shelters (with thermometers in them) outside. The teams investigating the physical properties of the shelter (color, slits, material) should find an open area away from buildings, preferably an open field. Teams investigating the placement of the shelter will split into two subgroups. One group will place its shelter in an appropriate area (grassy area, away from buildings). The other group will place its shelter in a non-ideal location. That is, to investigate the effects of shelter placement:
   - One shelter in an ideal location, one next to the sunny side of a building
   - One shelter in an ideal location, one in the middle of a parking lot, or other paved or asphalt surface
   - One shelter at 1.5 meters above the surface, the unmounted shelter on the ground at the base of the post
   - One shelter placed with its door facing north, the other one nearby with its door facing south.
5. After placing their shelters, students should record the temperature from each thermometer after about five minutes. They should then wait another five minutes and record the temperatures again. Temperatures should continue to be recorded at approximately five minute intervals, until the temperatures in the shelters have stabilized and do not change over two successive readings. Note that this may not necessarily take the same time for both shelters. That is, it may take one thermometer longer to reach the maximum temperature than the other. Therefore, it is important to check both thermometers.
6. Once the temperature has stabilized in both shelters, the students can bring their shelters and their recorded temperatures back to the classroom.
7. Each team should give a brief report of what it found to the entire class and then discuss why the temperatures may have behaved the way they did.
8. Each team should write a brief report showing its recorded temperatures. The team should discuss its findings in terms of how and why the particular parameter investigated affects the temperature.

Adaptations for Younger and Older Students

For younger students: The number of variables explored could be reduced to color, slits, placement near and away from buildings, and placement on natural and on concrete surfaces. Shelters could be placed on the ground instead of mounted on posts. (As long as they are all placed on the ground in the various areas, that factor will be consistent for all readings.)

For older students: Older students can explore which of the parameters is most important by making more than two shelters in each category. For example, they could test whether color is more important than slits by making one black and one white shelter without slits and one black and one white shelter with slits. See how many combinations they can come up with and which parameter has the greatest affect on the measured temperature. They can also explore what effect there is with the different shelter designs on a clear day versus a cloudy day, or a very calm day versus a windy day.

Student Assessment

Students' understanding of the importance of the shelter design and placement can be assessed in terms of:

- The conclusions they draw in their oral and written reports
- The understanding they show during the class discussions
- Their ability to deal with such additional questions as: What would be the effect if the white shelter became covered with a heavy layer of dust?
- The validity of the measurements they take.

Building a Thermometer

Purpose

To help students understand why and how a standard thermometer works

Overview

Students will construct a soda-bottle thermometer, which is similar to the thermometer used by GLOBE schools. Both are based on the principle that most substances expand and contract as their temperature changes. This experiment also demonstrates the principle of heat transfer.

Time

Two class periods

1. To do experiment - one class period
2. To discuss principles of expansion, contraction, and heat transfer through conduction and convection – 15 to 30 minutes
3. To record class data onto board or overhead and make graphs – 30 minutes
4. To have each group present to the class their results, ideas for other variables to test, and any problems that they encountered – 30 minutes

Level

Intermediate

Key Concepts

Substances expand and contract as the temperature changes.

Liquid-in-glass thermometers work on the basis of thermal expansion and contraction.

Conduction and convection are two forms of heat transfer.

Skills

Constructing an apparatus for an experiment

Conducting an experiment

Observing and *measuring*

Collecting, organizing and *recording* data

Working effectively in a group

Materials and Tools

(per group of students)

Ice

Water

One liter plastic soda bottle

Clear or white plastic drinking straw

Modeling clay. A one-pound block of modeling clay should be enough for 25 to 30 thermometers

Two 2-liter plastic soda bottles – the tops of these bottles need to be cut off

Scissors or knife to cut the top off the 2-liter plastic bottles

Food coloring (yellow does not work as well as red, blue, and green)

A watch or clock with a second hand

A metric ruler

A marker, grease pencil, or pen to mark the side of the straw

Building a Thermometer Activity Sheet

Preparation

Assemble materials.

Review principles of heat transfer.

Prerequisites

None

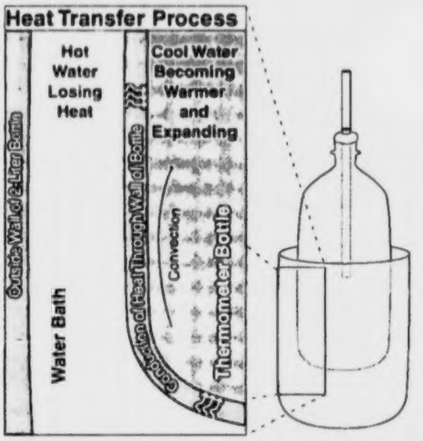
Background

For more information regarding how thermometers work, review *A Field View of the Atmosphere Investigation* in the *Welcome* section.

There are differences between the soda-bottle thermometer and the thermometer you use in GLOBE: the liquids used are different, the soda-bottle thermometer is not a closed system, and it lacks a numerical scale.

Several scientific principles are at work in this activity. One is the principle of expansion and contraction. Most substances expand when heated and contract when cooled. Over the range of temperatures in this experiment, water too expands when heated and contracts when cooled. (As water approaches its freezing point, it again expands.)

Figure ATM-L-4


Heat Transfer Process
Hot Water Losing Heat
Cool Water Becoming Warmer and Expanding
Outside Wall of 2-Liter Bottle
Conduction of Heat Through Wall of Bottle
Convection
Thermometer Bottle
Water Bath

Substances expand when heated because their kinetic energy, or energy of movement, increases with temperature. The molecules move faster and spread farther apart, causing the material to expand. When the substance is cooled, molecular movement decreases and the substance contracts.

In the case of water, the coefficient of expansion is quite small, so the volume of the water increases by only a very small percentage. Nonetheless, because all of the increase in volume is channeled into the small-diameter straw, the expansion can be seen.

This experiment also illustrates heat transfer by conduction. Conduction occurs when energy is transferred from one molecule to the next by direct contact, such as when the metal handle of a pan becomes hot. Metals are good conductors of heat. Wood is a poor conductor. In this experiment, the warm water in the outer container transfers its heat by conduction through the plastic wall of the one-liter bottle to the water in the inner bottle.

Although heat transfer by conduction can take place in solids, liquids, and gases, it is most efficient in solids and liquids. In the atmosphere, the air molecules in contact with the ground are heated by conduction. As these air molecules gain energy, they become less dense and start to rise.

Convection is the large-scale movement of a liquid or a gas which acts to redistribute heat throughout an entire volume. A common example of convection is water boiling in a pot. In this case, the water in contact with the bottom of the pot (where the heat source is) becomes heated and less dense than the water on top of it. This hot water rises, cooler water sinks and is then heated by contact with the bottom of the pot.

Preparation

This activity works well in teams of two or three students. Here are some job assignments and descriptions:

Student 1 Assembler - gathers materials and assembles the thermometer

Student 2 Timer/reporter – keeps track of 2-minute intervals when the experiment starts – makes marks on the straw showing how much the water has moved – measures the straw at the end of the experiment and tells the recorder the measurements – reports to the class the results of the experiment

Student 3 Recorder – records the measurements that the timer has made – also transfers the group's measurements onto the data sheets.

Make a copy of the Building a Thermometer Activity Sheet for each group of students.

BEST COPY AVAILABLE

The teacher should assemble materials before the class starts. If small groups are to be used, they should be assigned in advance. Students should bring in the 1-liter and 2-liter soda bottles. Allow a week or so to collect the necessary materials if students are supplying the bottles. Be sure to review the possible problems below before doing the experiment in class.

Be sure to understand the principles of heat transfer (conduction and convection) and the expansion and contraction of materials. Some examples of each in different situations would be helpful for a discussion. You may need to review how to measure in millimeters with the students.

Team Data Sheet *measurements in millimeters*

2 minutes	
4 minutes	
6 minutes	
8 minutes	
10 minutes	

Class Data Sheet

	Group A	B	C	D	Average
2 minutes					
4 minutes					
6 minutes					
8 minutes					
10 minutes					

What To Do and How To Do It

This activity can be done as a demonstration but is probably more effective if students or groups of students make their own thermometers. These instructions also appear on the *Building a Thermometer* Activity Sheet in the *Appendix* which can be copied and distributed to students.

Building the Thermometer

1. Fill the 1-liter soda bottle to the very top of the lip with cold tap water.
2. Add four drops of food coloring. This makes the water line easier to see. Blue, green, or red work best.
3. Roll some modeling clay into a small ball about 25 mm in diameter. Then roll it out so that it forms a cylinder about the length and diameter of a pencil. Flatten the pencil-shaped clay into a thick ribbon. Wrap the ribbon around the mid-point of the straw. See Figure ATM-L-5.

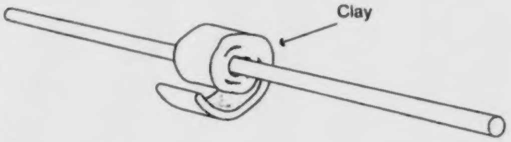


Figure ATM-L-5

4. Place the straw into the bottle and use the clay to seal off the bottle. Be careful not to pinch the straw closed. You also do not want any holes or cracks in the clay that would allow water to escape. One half of the straw will be inside the bottle and one half will be outside the bottle. Press the clay plug into the neck of the bottle far enough to force the water level up into the straw so that it can be seen. See Figure ATM-L-6.

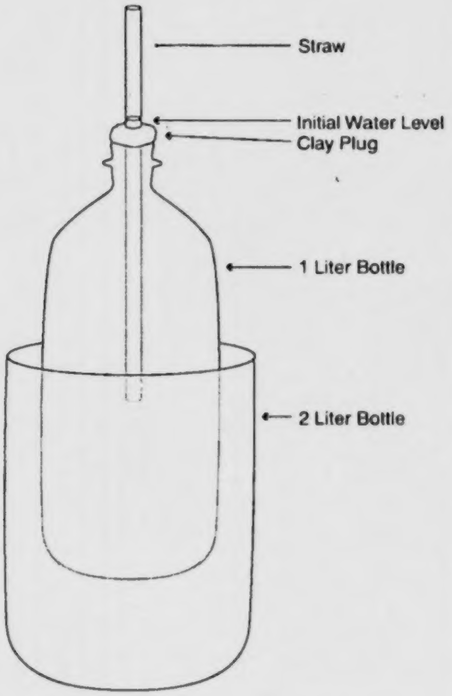
Experiment

1. Place the filled one-liter bottle (soda-bottle thermometer) into one two-liter plastic bottle container. Place a mark on the straw where you see the water line.
2. Fill the 2-liter container with hot tap water. Wait two minutes. Mark the straw at the water line. Repeat this marking

every two minutes, for ten minutes. At the end of the ten minutes, use a ruler to measure the distance of each mark from the original water mark at the bottom of the straw. Record your measurements on the team data sheet.

Watch closely for any changes. Do you see any? Describe what you observe.

3. Put ice and cold water into the second two-liter container.
4. Place the thermometer bottle into the ice water. Record your observations.



5. What happens to the water level in the straw when the thermometer is placed in hot water? (Answer: It rises about 4 cm if there's a 25 degree C difference.) Why? What happens to the water level when the thermometer is placed in cold water? (Answer: It falls.) Why?
6. Explain why you think this is happening.
7. Using your answer to question 6, how does the maximum-minimum thermometer, used for the noon temperature measurements for GLOBE, work?
8. What are two other things (variables) that, if changed, might cause this experiment to work differently? (A few answers: the amount of water touching the soda-bottle thermometer, the temperature of the water, the size of the container, the diameter of the straw.)
9. Graph the measurements that you recorded on your team data sheet. The x-axis (horizontal) should be the time (in minutes) and the y-axis (vertical) should be your measurements from the original line before the hot water is added (in millimeters). Be sure to give your graph a title and to label the axes of the graph so that someone else could understand it.
10. Make a class data sheet on a chalkboard or on a sheet of poster paper. Record your data on the Class Data Sheet. Combine your data with that of your classmates to find the average movement of water for each two-minute time period.
11. Add the average figures for the movement of water to your graph. Be sure to label this new line. How is the graph of your measurements different from the graph of the class average?
12. Explain the graph. What story does your graph tell? Can you draw any conclusions?
13. Why might it be important to have more than one trial when you are drawing conclusions?

Possible Problems with the Experiment

- The seal with the modeling clay has cracks in it, allowing the water to escape
- If the 1-liter water bottle is not filled to the top, it takes a longer time for the water to move up the straw. Indeed, the water may not move up the straw at all.
- There is not enough of a temperature difference between the water in the 1-liter bottle and the water in the 2-liter bottle. A 25 degree Celsius or larger difference is optimum. If there is a smaller difference, you will not get very large movements on

the straw. Hot tap water and cold tap water should have enough of a difference for the experiment to work.

- Students will forget to mark the beginning level in the straw. Be sure that they understand that the mark should be made immediately after placing the 1-liter bottle into the 2-liter bottle, before adding the hot water.
- If you have trouble getting or keeping ice in the classroom, you can omit this part of the experiment or show it as a demonstration.

Adaptations for Younger and Older Students

For younger students: Younger students can make the thermometer apparatus and observe the movement of the water in the straw, but not mark the water level at two-minute intervals. The teacher should cut the two-liter plastic container ahead of time.

For older students: Other variables could be tested, such as different size straws, larger or smaller containers for the hot water, or different size containers for the thermometers. The students could design their own experiment, conduct it, and present their findings to the class. They could calibrate their thermometer with a standard thermometer.

Further Investigations

1. Use a standard thermometer to measure the temperature of the water in the inside of the soda-bottle thermometer and compare it to the temperature of the water outside the thermometer. Does the amount of water movement in the straw change when there are different temperatures? Perform an experiment, keep records, and present your findings to the class.
2. Does the size of the containers affect the way the thermometer works? Design an experiment that tests this concept, do the experiment, and make a chart showing your results.
3. Go to the library and research what materials are used to make different thermometers. Be sure to find out the different principles on which they operate. Present your findings to the class.
4. Call the local weather offices or television or radio stations and see what type of thermometers are used there. Take a trip to visit the weather station. Take pictures and make a poster to share with your class.
5. Make thermometers using different diameters of straws and see if there are any differences. What do you think might have caused any differences you see? Would this have an effect on the construction of real thermometers?
6. Find out how scientists record the temperature at different depths of the ocean. On a map of the oceans, show the average water temperature. Make a chart to share with the class.

Student Assessment

Students should be able to answer the questions in the experiment on the student activity sheet. They should also be able to explain how a thermometer works in class or on a quiz.

Building a Thermometer Activity Sheet

Duplicate and distribute to students.

Purpose

To help you understand how and why a liquid-in-glass thermometer works.

Overview

The soft drink bottle thermometer that you construct in this activity is similar to the thermometer you use in the GLOBE Instrument Shelter. However, there are differences. Both use liquids, but the liquids are different. Do you know what liquid is in the standard GLOBE thermometer? Also, the thermometer you will make has no degree markings. But the principles of operation are the same for both types of thermometers.

The thermometer you use for measurements and the instruments you will build are both based on the principle that substances expand and contract as their temperature changes.

This lab also demonstrates the principle of heat transfer. When a warm object is placed against a cold object heat is transferred from the warm object to the cold object by conduction. For example, in the winter if you place your bare hand on the fender of an automobile, your hand transfers heat to the metal by conduction.

Usually when you work in a job, you are part of a team. In this activity you will also be part of a team. Here are your job descriptions:

Student 1 – assembler - gathers materials and assembles the thermometer
Student 2 – timer/reporter - uses clock or watch to keep track of 2-minute intervals when the experiment starts - makes marks on the straw showing how much the water has moved - measures the straw at the end of the experiment and tells recorder the measurements - reports to the class the results of the experiment
Student 3 – recorder - records the measurements that the timer has made - also transfers the group's measurements onto the class chart

Materials and Tools

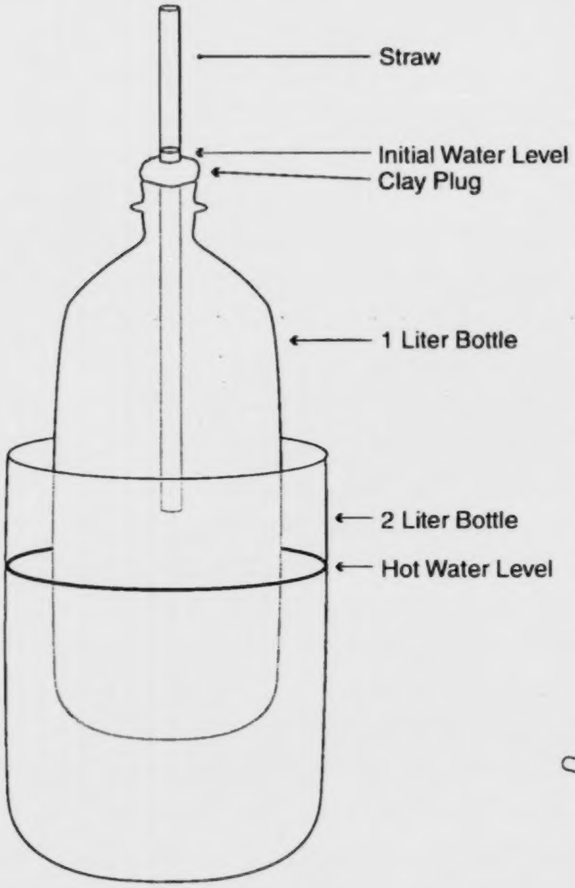
(per group of students)

Ice
Water
One liter plastic soda bottle
Clear or white plastic drinking straw
Modeling clay (a ball about 25 mm in diameter)
Scissors or knife to cut the top off the two liter plastic bottle
2 two-liter plastic soda bottles - the top of the bottle needs to be cut off so that it is used as a container to hold water and the 1 liter plastic soda bottle
Food coloring (yellow doesn't work as well as red, blue, and green)
Watch or clock with second hand
Metric ruler
Marker, grease pencil, or pen to make marks on the side of the straw

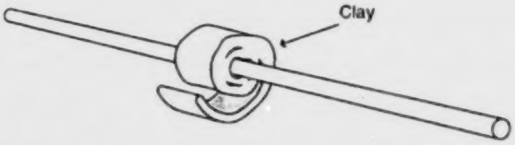
Duplicate and distribute to students

Building the Thermometer

1. Fill the one liter soft drink bottle to the very top of the lip with cold tap water.
2. Add four drops of food coloring – this helps make the water line easier to see. Blue, green, or red work best.



3. Roll some modeling clay into a small ball about 25 mm in diameter. Then roll it out so that it forms a cylinder about the length and diameter of a pencil. Flatten the pencil-shaped clay into a thick ribbon. Wrap the ribbon around the midpoint of the straw.
4. Place the straw into the bottle and use the clay to seal off the bottle. In doing this, be careful not to pinch the straw closed. You also do not want any holes or cracks in the clay that would allow water to escape. One half of the straw will be inside the bottle and one half will be outside the bottle. Press the clay plug into the neck of the bottle far enough to force the water level up into the straw so that it can be seen.



Experiment

1. Place the filled one liter bottle (the soft drink bottle thermometer) into the empty two liter plastic bottle container. Place a mark on the straw where you see the water line.
2. Fill the two liter container with hot tap water. Wait two minutes. Mark the straw at the water line. Repeat this marking every two minutes, for ten minutes. At the end of ten minutes use a ruler to measure the distance of each mark from the original water mark at the bottom of the straw. Record your measurements on the team data sheet, below.

Duplicate and distribute to students.

Team Data Sheet

Time	Measurements in millimeters
2 minutes	
4 minutes	
6 minutes	
8 minutes	
10 minutes	

Watch closely for any changes. Do you see any? Describe what you observe.

3. Put ice and cold water into the second two-liter container.
4. Place the thermometer bottle into the ice water. Record your observations.

5. What happens to the water level in the straw when the thermometer is placed in hot water?

What happens to the water level in the straw when the thermometer is placed in cold water?

Duplicate and distribute to students.

6. Explain why you think these changes happen.

7. Using your answers to question 6, how does the maximum-minimum thermometer used for the GLOBE measurements work?

8. What are two other things (variables) that, if changed, might cause this experiment to work differently?

9. Graph the measurements that you recorded in your team data sheet at step number 2. The x-axis (horizontal) should be the time (in minutes) and the y-axis (vertical) should be your measurements (in millimeters) from the original line before the hot water was added. Be sure to give your graph a title and to label the axes of the graph so that someone else could understand it.

10. Record your data on the Class Data Sheet on the board or as your teacher instructs. Combine your data with that of your classmates to find the average movement of water for each two-minute time period.

11. Add the average figures for the movement of water to your own graph. Be sure to label this new line. How is the graph of your measurements different from the graph of the class average?

12. Explain the graph. What story does your graph tell? Can you draw any conclusions?

13. Why might it be important to have more than one trial when you are drawing conclusions?

Land, Water, and Air

Purpose

To help students understand that land and water heat and cool at different rates and that the properties of soil and water influence the heating of air above them

Overview

Students measure temperature changes in soil, water, and air as they are exposed to the heating action of the sun.

Time

Three to four hours total

one to two hours of actual time on task

Level

Intermediate and advanced

Key Concepts

Different substances, such as soil, water, and air, transfer energy and heat at different rates

Skills

Designing and *conducting* an experiment

Measuring and *recording* data

Organizing data in tables

Graphing

Working effectively in groups

Materials and Tools

(per group of students)

Two plastic buckets at least 30 cm tall

A centimeter ruler

Six thermometers

A means to suspend the thermometers over the buckets, such as string and dowels

Preparation

Arrange for an outdoor area in which to conduct the experiment. (This activity could be performed indoors by substituting a strong artificial light source for the sunlight.) This experiment gives the best results on a sunny, warm day. Divide the students into small working groups. You may want to demonstrate the activity first so that all students understand how to conduct the experiment.

Prerequisites

None

Background

One of the important reasons why we have different kinds of weather throughout the world is because land and water heat and cool at different rates.

For example, afternoon thunderstorms in Florida are often initiated by the fact that during the day the land heats up faster than the water does. (To understand more about this, students should research what causes sea breezes.) In parts of the world that experience monsoons (wind systems that reverse direction seasonally), the rainy part of the monsoon season is characterized by alternating periods of active (rainy) and non-active (not-rainy) weather depending on whether the land is dry or wet.

Students may have observed a difference in the heating and cooling rates of land relative to water if they have ever run barefoot across a beach to the water in the middle of a warm, sunny afternoon. They probably remember how hot the land was and how cool and refreshing the water was. If they were at the beach until after sunset and walked barefoot across the beach to the water, they might remember that at this time of day, it is the beach that feels cool, while the water feels warm. Students can study this land/water difference with a simple experiment.

What To Do and How To Do It

Fill one bucket with soil to a depth of approximately 15 centimeters. Fill the other bucket to the same depth with cool water (as from an outdoor faucet). Set both buckets out in the sun. In each bucket suspend a thermometer one cm above, one cm below, and eight cm below the surface. Try to position the thermometers so that the sunlight is not shining directly on the bulb or the glass tube. Allow time for the thermometer temperatures to stabilize. Record the initial thermometer readings.

Read the temperature of each thermometer at two minute intervals for 20 minutes. Then read the temperatures at one, two, and three hours.

Questions for Discussion

Is the temperature of the soil one cm below the surface warmer than it was when students set out the buckets three hours ago? Is the surface temperature of the water warmer now than it was three hours ago? Why?

Which temperature reading is higher at a depth of 8 cm, that of the soil or that of the water? What conclusions can students draw from this experiment?

What your students should have found was that the soil's surface was much warmer at one cm than that of the water at one cm. On the other hand, the water was warmer at a depth of 8 cm after 3 hours than the soil at a depth of 8 cm. The temperatures at one cm above the surface should be higher for the soil than for the water.

Liquid water molecules move much more freely than the molecules that make up soil. Therefore, water can distribute heat throughout a greater volume than can soil. That is why, after three hours in the sun, the water in the bucket was warmer at the 8 cm depth than was the soil. After sunset, the heat absorbed by soil quickly escapes to the atmosphere, and the land cools rapidly. However, although water heats up more slowly than land, once it is heated it takes longer to cool. If students were to repeat the measurements several hours after sunset, they would find that the water temperature at one cm depth was higher than that of the soil at one cm depth.

Cloud Watch

Purpose

To track clouds and weather, and begin to understand the connection between the two

Overview

Students observe clouds over a five-day period and correlate these observations with the weather.

Time

Ten minutes per day for five days; plus perhaps half of one class period to discuss

Level

All

Key Concepts

Relationship of clouds and changes in clouds to weather

Skills

Systematically *observing* over a period of time

Correlating one observed phenomenon with another

Materials and Tools

GLOBE Science Notebooks and cloud charts

Preparation

Divide the students into small working groups. Discuss how they will record their observations in their GLOBE Science Notebooks.

Prerequisites

None

What To Do And How To Do It

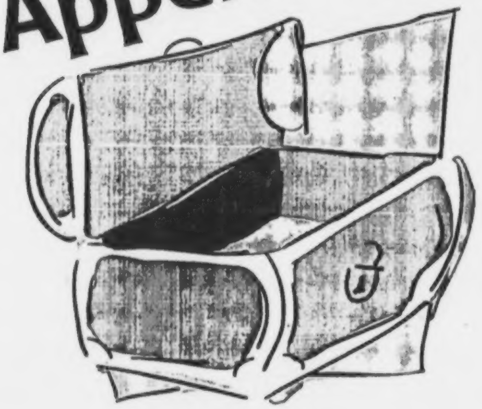
Over a five-day period, students should carefully look at the clouds and write down what they see. If they do not yet know the names of the clouds, they can write down what the clouds look like. It is best if they can check the sky three times per day: once in the morning (on the way to school); once in the early afternoon (around lunchtime); and once in the late afternoon or evening (perhaps on the way home from school). The exact times of each observation are not critical, although it will help if the observations are made at roughly the same time each day. (For example, the morning observations should all be made around 8 am, rather than at 7 am one day, and 10 am the next day. The same is true for the noontime and evening observations).

At the end of each day, students should also record the weather for that day. Was it a rainy morning and clear afternoon? Did it snow all day? Was it calm and humid? The students do not need to quantify their weather reports (i.e., they don't have to write down "21 millimeters of rain" or "79% relative humidity"), but should describe the weather as completely and clearly as possible.

As the students record their cloud and weather observations, they should look for any patterns. For example, are cirrus clouds (thin, wispy clouds) in the morning typically followed by afternoon thunderstorms? Are the small puffy clouds (cumulus) ever associated with precipitation?

After a week of recording clouds and weather, ask students to use their observations to predict what the weather will be like tomorrow. Ask them to explain why they made their predictions. Have each student keep track of how well they do in forecasting the weather. They may develop a new respect for the difficulty of forecasting!

Appendix



Data Work Sheet

Observing Cloud Type

Glossary

GLOBE Web Data Entry Sheets

Atmosphere Investigation

Data Work Sheet

School Name ______________________________

Observer Names ______________________________

Measurement method for pH: ☐ paper ☐ pen ☐ meter

	Sat.	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.
Date							
Hour (Universal Time)							
Observer Names							

Cloud type (Check all types seen)

	Sat.	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.
Cirrus	☐	☐	☐	☐	☐	☐	☐
Cirrocumulus	☐	☐	☐	☐	☐	☐	☐
Cirrostratus	☐	☐	☐	☐	☐	☐	☐
Altostratus	☐	☐	☐	☐	☐	☐	☐
Altocumulus	☐	☐	☐	☐	☐	☐	☐
Stratus	☐	☐	☐	☐	☐	☐	☐
Stratocumulus	☐	☐	☐	☐	☐	☐	☐
Nimbostratus	☐	☐	☐	☐	☐	☐	☐
Cumulus	☐	☐	☐	☐	☐	☐	☐
Cumulonimbus	☐	☐	☐	☐	☐	☐	☐

Cloud Cover (Check one)

	Sat.	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.
Clear	☐	☐	☐	☐	☐	☐	☐
Scattered	☐	☐	☐	☐	☐	☐	☐
Broken	☐	☐	☐	☐	☐	☐	☐
Overcast	☐	☐	☐	☐	☐	☐	☐

Rainfall

	Sat.	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.
Number of days rain has accumulated							
Rainwater in rain gauge (mm)*							

** Remember:*
Record 0.0 when there has been no rainfall or snowfall.
Record M if the measurement is lost or missing for this day.
Record T for trace amount of rainfall (less than 0.5 mm) or snowfall (too small to measure).

Atmosphere Investigation Data Work Sheet (Continued)

	Sat.	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.
Date							
Hour (Universal Time)							
Observer Names							

Snowfall

Total depth of snow on the ground: (mm)							
Number of days snow has accumulated on the snowboard: (mm)							
Depth of new snow on the snowboard: (mm)*							
Daily liquid equivalent of the new snow: (mm)							

Precipitation pH

pH of the rain or melted snow:							

Maximum, Minimum, and Current Temperatures

Current air temperature: (in deg rees C)							
Maximum daily air temperature: (in deg rees C)							
Minimum daily air temperature: (in deg rees C)							

Notes: (Unusual conditions.)

** Remember:*
Record 0.0 when there has been no rainfall or snowfall.
Record M if the measurement is lost or missing for this day.
Record T for trace amount of rainfall (less than 0.5 mm) or snowfall (too small to measure).

Observing Cloud Type

There are five descriptive terms for the various types of clouds:

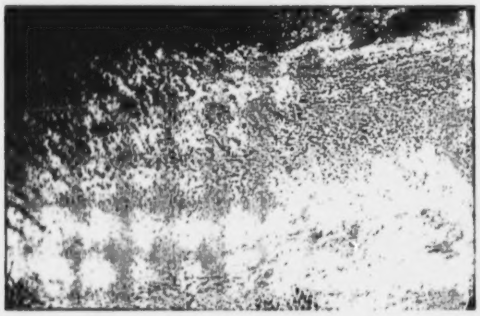
CIRRO or high clouds
ALTO or middle clouds
CUMULUS or white puffy clouds
STRATUS or layered clouds
NIMBUS or clouds from which precipitation is falling

The following ten types of clouds, named using the above terms, are to be used when reporting the cloud type for your area:

High Clouds

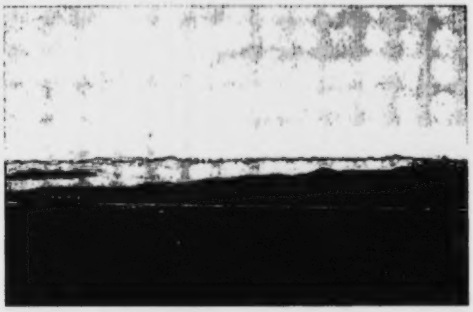
Cirrus

These clouds look like white delicate feathers. They are generally white wispy forms. They contain ice crystals.



Cirrocumulus

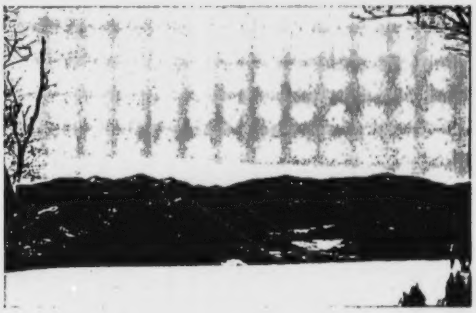
These clouds are thin white layers with a texture giving them the look of patches of cotton or ripples without shadows. They contain primarily ice crystals and perhaps some very cold water droplets.



Cirrostratus

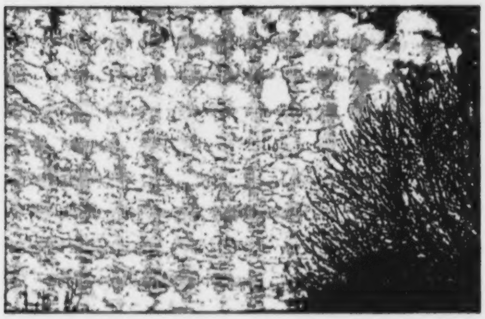
These clouds are a thin, almost transparent, whitish layer made up of ice crystals. They may totally or partly cover the sky and can create a halo appearance around the sun.

Middle Clouds



Altostratus

These clouds form a bluish or grayish veil that totally or partially covers the sky. The light of the sun can be seen through them but there is no halo effect.



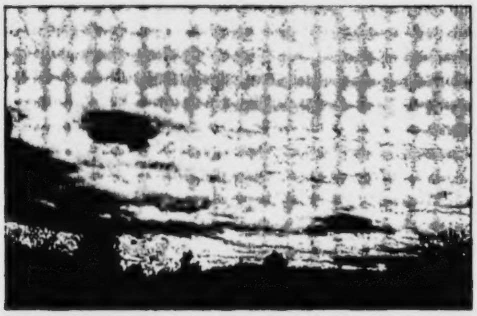
Altocumulus

These clouds look like waves of the sea with white and gray coloring and shadows. They contain mostly water droplets and perhaps some ice crystals.

Low Clouds

Stratus

These clouds are gray and lie very close to the surface of the Earth. They usually look like a sheet layer but sometimes are found in patches. They rarely produce precipitation.

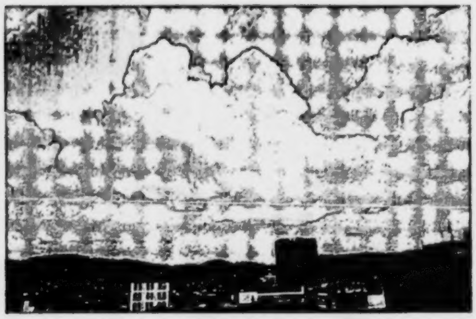


Stratocumulus

These clouds are a gray or whitish color. The bases of these clouds tend to be more round than flat. They can be formed from old stratus clouds or from cumulus clouds that are spreading out. Their tops also tend to be mostly flat.

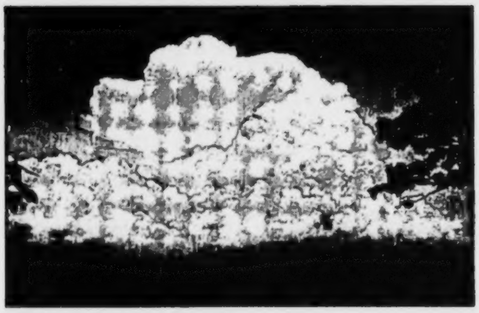
Nimbostratus

This is a very dark and gray-colored cloud layer that blots out the light of the sun. It is massive and has a continuous fall of precipitation.



Cumulus

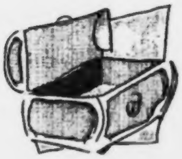
These clouds have a flat base and a dense, mound-shaped top that resembles a large cauliflower. Where the sun hits these clouds they are a brilliant white. The base tends to be a darker gray. They generally do not produce precipitation.



Cumulonimbus

These are large, heavy, and dense clouds. They have a generally flat, dark surface with very tall and large tops like the shape of a massive mountain or anvil. These clouds are often associated with lightning, thunder and sometimes hail. They may also produce tornados.

Glossary



acidic precipitation

Rain or snow with a pH lower than 5.6, which is the naturally occurring value for rain or snow in equilibrium with the carbon dioxide in the air.

aerosols

Liquid or solid particles dispersed or suspended in the air. This term is not used for rain or cloud droplets nor for ice crystals.

air temperature

A measure of the degree of hotness or coldness of the air.

cloud

A visible form of condensed water in the atmosphere. This may include water droplets and ice crystals. In addition, clouds may include aerosols or solid particles such as those present in fumes, smoke or dust.

cloud cover

Refers to the amount (in tenths) of the sky which is covered by clouds.

current temperature

The temperature at the time the thermometer is read.

high clouds

These clouds, found above 6,000 m, are made up of mostly ice crystals.

liquid precipitation

Includes rainfall and drizzle.

local solar noon

Solar noon is used in this Teachers' Guide as the time when the sun appears to have reached its highest point in the sky during the day. It occurs halfway between sunrise and sunset.

low clouds

Low clouds, found below 2,000 m, mostly contain water but also can be made up of snow and ice particles.

maximum temperature

The highest temperature that has occurred since the preceding temperature reading and resetting of the thermometer.

meniscus

The curved surface of a liquid confined in a narrow tube due to the adhesion of the liquid to the interior surface of the tube.

middle clouds

These clouds are made up of mostly liquid water. The base of these clouds can range in height from 2,000 m to 6,000 m.

minimum temperature

The lowest temperature that has occurred since the preceding temperature reading and resetting of the thermometer.

precipitation

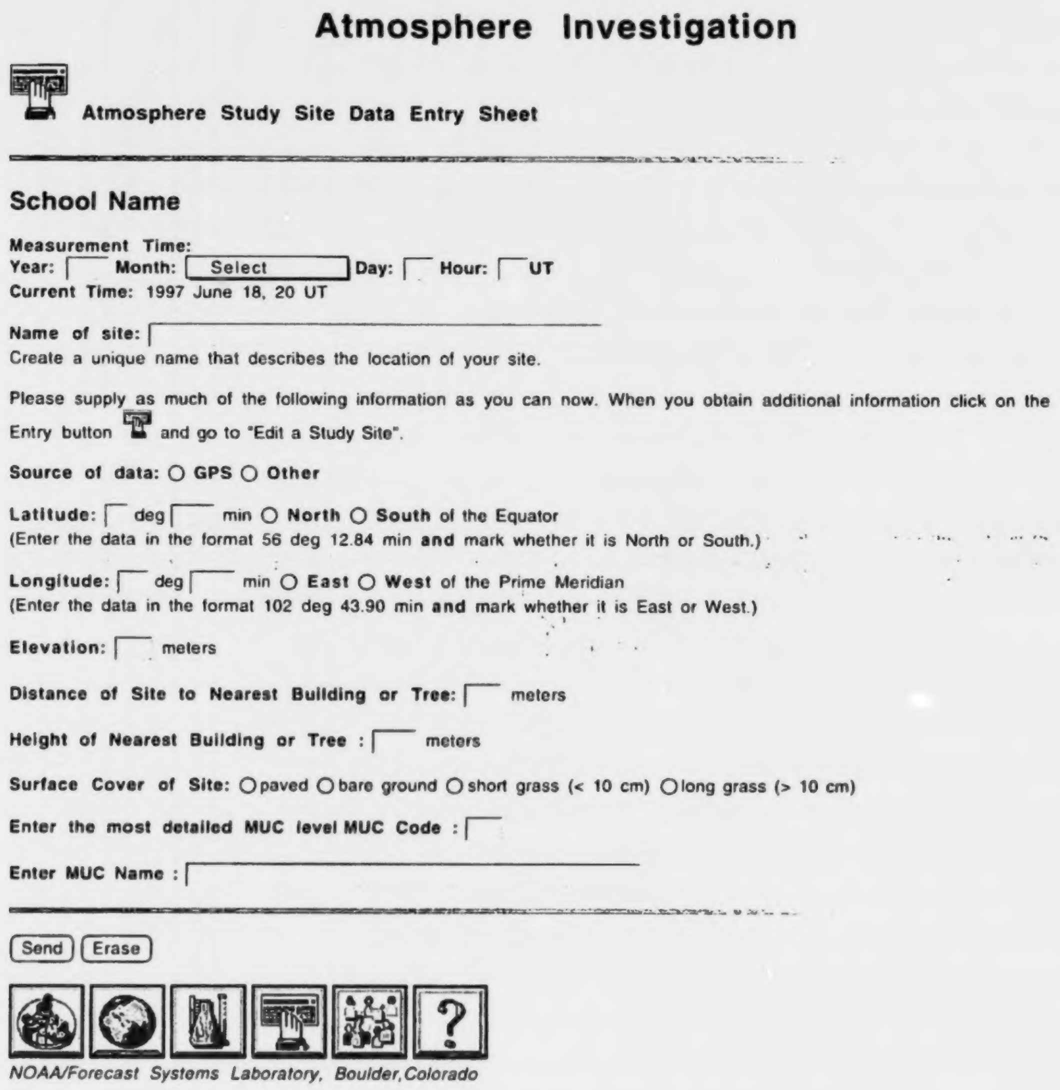
Refers to any or all forms of liquid or solid water particles that fall from the atmosphere and reach Earth's surface.

solid precipitation

Includes snow, ice pellets, hail, ice crystals, and, for the purpose of precipitation measurements, freezing rain.

water equivalent

The liquid content of a sample of solid precipitation. This is determined by melting the sample and measuring the resulting amount of water.



Atmosphere Investigation

Atmosphere Study Site Data Entry Sheet

School Name

Measurement Time:
Year: ☐ **Month:** Select **Day:** ☐ **Hour:** ☐ **UT**
Current Time: 1997 June 18, 20 UT

Name of site: ☐
Create a unique name that describes the location of your site.

Please supply as much of the following information as you can now. When you obtain additional information click on the Entry button and go to "Edit a Study Site".

Source of data: ○ **GPS** ○ **Other**

Latitude: ☐ deg ☐ min ○ **North** ○ **South** of the Equator
(Enter the data in the format 56 deg 12.84 min **and** mark whether it is North or South.)

Longitude: ☐ deg ☐ min ○ **East** ○ **West** of the Prime Meridian
(Enter the data in the format 102 deg 43.90 min **and** mark whether it is East or West.)

Elevation: ☐ meters

Distance of Site to Nearest Building or Tree: ☐ meters

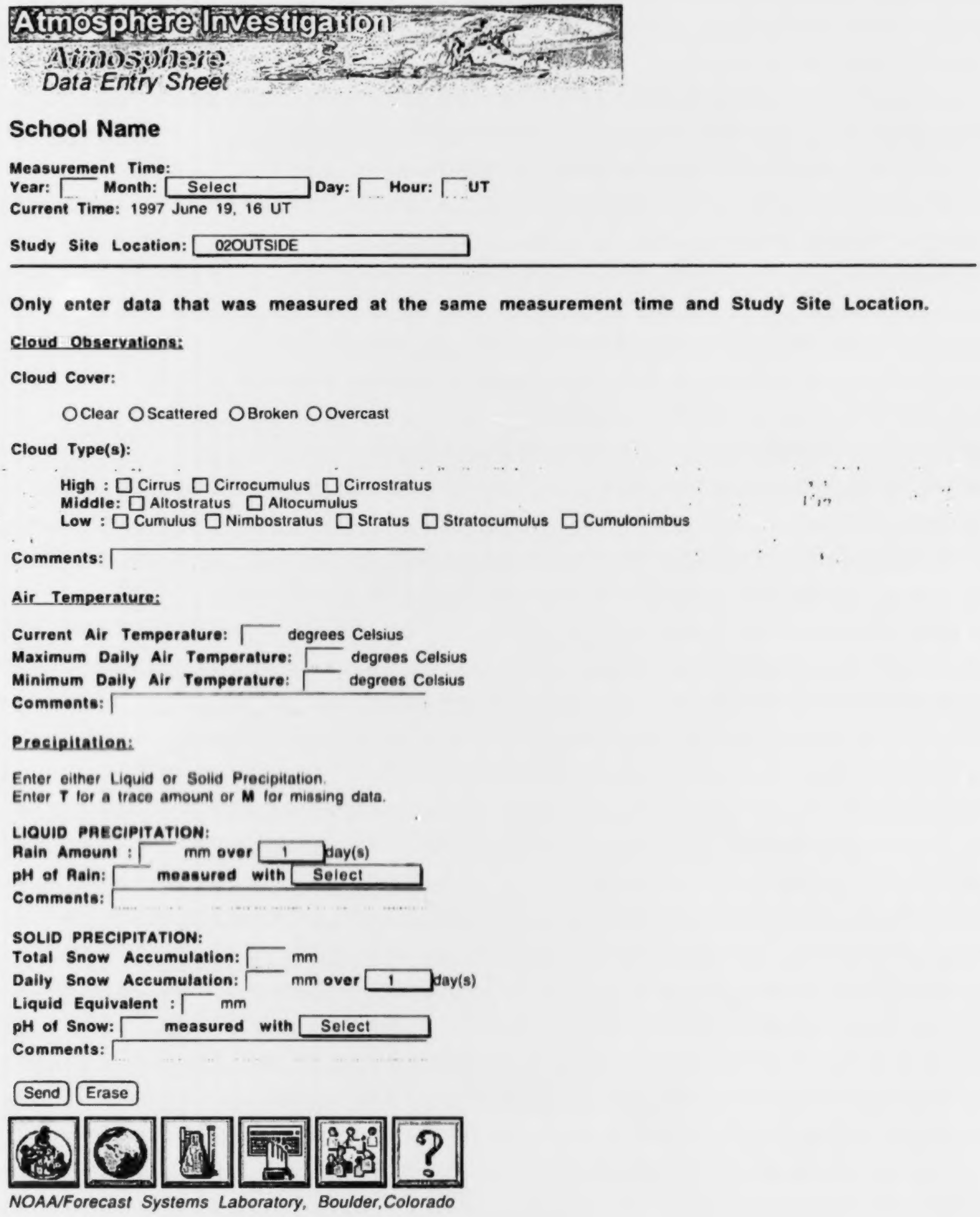
Height of Nearest Building or Tree : ☐ meters

Surface Cover of Site: ○ paved ○ bare ground ○ short grass (< 10 cm) ○ long grass (> 10 cm)

Enter the most detailed MUC level MUC Code : ☐

Enter MUC Name : ☐

NOAA/Forecast Systems Laboratory, Boulder,Colorado



School Name

Measurement Time:
Year: ☐ **Month:** Select **Day:** ☐ **Hour:** ☐ **UT**
Current Time: 1997 June 19, 16 UT

Study Site Location: 02OUTSIDE

Only enter data that was measured at the same measurement time and Study Site Location.

Cloud Observations:

Cloud Cover:

○ Clear ○ Scattered ○ Broken ○ Overcast

Cloud Type(s):

High : ☐ Cirrus ☐ Cirrocumulus ☐ Cirrostratus
Middle: ☐ Altostratus ☐ Altocumulus
Low : ☐ Cumulus ☐ Nimbostratus ☐ Stratus ☐ Stratocumulus ☐ Cumulonimbus

Comments: ☐

Air Temperature:

Current Air Temperature: ☐ degrees Celsius
Maximum Daily Air Temperature: ☐ degrees Celsius
Minimum Daily Air Temperature: ☐ degrees Celsius
Comments: ☐

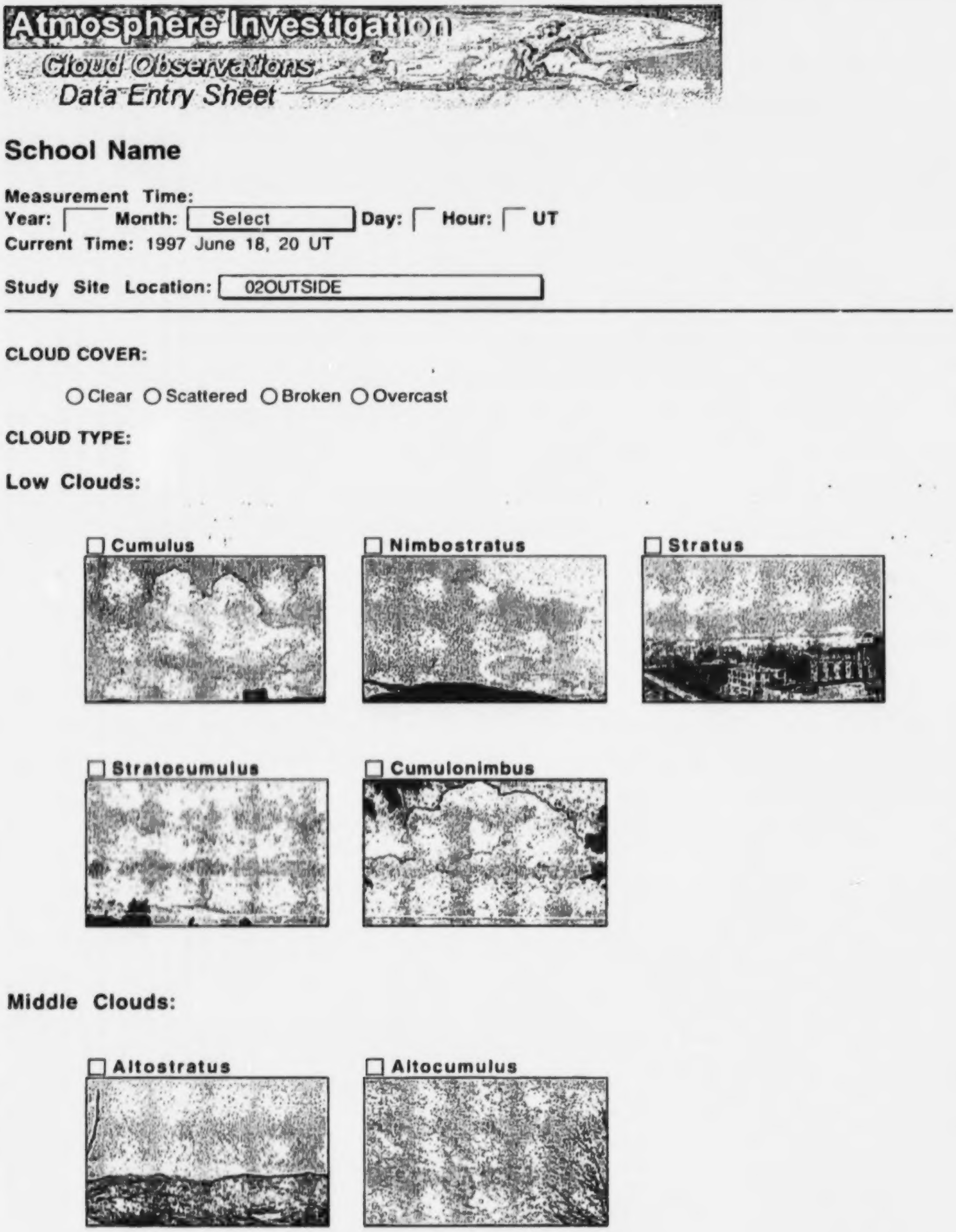
Precipitation:

Enter either Liquid or Solid Precipitation.
Enter **T** for a trace amount or **M** for missing data.

LIQUID PRECIPITATION:
Rain Amount : ☐ mm over 1 day(s)
pH of Rain: ☐ **measured with** Select
Comments: ☐

SOLID PRECIPITATION:
Total Snow Accumulation: ☐ mm
Daily Snow Accumulation: ☐ mm over 1 day(s)
Liquid Equivalent : ☐ mm
pH of Snow: ☐ **measured with** Select
Comments: ☐

NOAA/Forecast Systems Laboratory, Boulder, Colorado



Atmosphere Investigation

Cloud Observations

Data Entry Sheet

School Name

Measurement Time:

Year: ☐ **Month:** Select **Day:** ☐ **Hour:** ☐ **UT**

Current Time: 1997 June 18, 20 UT

Study Site Location: 02OUTSIDE

CLOUD COVER:

○ Clear ○ Scattered ○ Broken ○ Overcast

CLOUD TYPE:

Low Clouds:

☐ **Cumulus** ☐ **Nimbostratus** ☐ **Stratus**

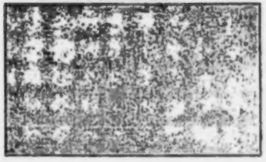
☐ **Stratocumulus** ☐ **Cumulonimbus**

Middle Clouds:

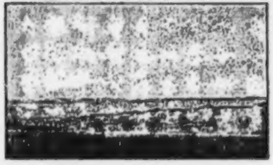
☐ **Altostratus** ☐ **Altocumulus**

High Clouds:

Cirrus



Cirrocumulus



Cirrostratus

Comments:

NOAA/Forecast Systems Laboratory, Boulder,Colorado

Hydrology Investigation

A GLOBE™ Learning Investigation

Hydrology Investigation at a Glance

Protocols

Weekly Measurements:

Transparency
Water Temperature
Dissolved Oxygen
pH
Electrical Conductivity
Salinity
Alkalinity
Nitrate

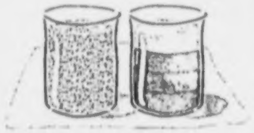
Suggested Sequence of Activities

Read the scientists' letter before you head out into the field.

Water Walk sets the stage for developing interest in water quality/chemistry.

Model Your Watershed provides the big picture view of students' watershed and the water study site in relation to this watershed.

Practicing the Protocols guides students through learning how to use the instruments and following the protocols so they collect reliable data.



Begin Field Sampling: your class goes to its site and begins the weekly measurements for water.

Focus on Key Science Ideas by performing the following Learning Activities:

Water Detectives and *The pH Game* introduce students to key water chemistry variables and to the need for instrumentation to make certain measurements.

Water, Water Everywhere! How Does it Compare? shows students how to analyze trends in their data and compare their data to other schools' data. This activity should be ongoing and repeated regularly as the data accumulates.

Modeling Your Water Balance lets students explore how to use their data for modeling.

Macroinvertebrate Discovery explores the connection between water measurements and aquatic life. This activity could be ongoing and repeated as conditions change.

Start linking water data to other GLOBE data.

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H_2O

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Duplicate and distribute to students.

Scientists' Letter to Students

Dear GLOBE Students,

We are the principal scientists on the GLOBE Hydrology and Water Chemistry investigation, and we welcome you to the program. You are participating in a scientific program that addresses a critical gap in our knowledge about the Earth.

Hydrology is the study of water, one of the most critical resources on Earth. Water is essential to all life. You and your fellow students in schools around the world will collect what should be the broadest set of measurements on water quality compiled to date. This GLOBE program will result in more bodies of water being sampled at the same time than ever before. We hope you find this planetary connection exciting, challenging and important.

In measuring the quality of water on your study site, you will learn much about an important part of your local environment and how it changes throughout the year.

We are very interested in your data and are excited about using the data to answer questions about planetary and local hydrology. So please let us hear from you. As the year progresses, you will hear from us with suggestions about how to interpret your data. We hope that together we can find answers to important water-quality questions.

Very truly yours,

Drs. Roger C. Bales & Martha H. Conklin
Professor & Associate Professor
University of Arizona
Tucson, Arizona, U.S.A

Duplicate and distribute to students

Meet Dr . Roger C. Bales and Dr . Martha H. Conklin

Roger C. Bales and Martha H. Conklin teach and conduct research in hydrology and water resources at the University of Arizona in Tucson, Arizona, U.S.A.

GLOBE: *You are co-principal investigators for GLOBE's Hydrology measurements and you're married to each other?*

Dr. Conklin: Right. We have a two-year old girl and just had a little boy in January.

GLOBE: *You are a husband-and-wife scientific team. How did you meet?*

Dr. Conklin: We met at graduate school. We were both interested in water chemistry.

GLOBE: *Water is $H_2 0$. What is your interest in its chemistry?*

Dr. Bales: It's the impurities in water that are of interest and concern.

Dr. Conklin: You won't find pure water in nature because it is a universal solvent. All kinds of materials either dissolve in it or are deposited into it. A purpose of GLOBE is to understand what occurs in water and what happens when substances like chemicals are added to it.

Dr. Bales: According to the head of the U.S. Environmental Protection Agency, about 40% of the surface waters in this country are not fishable and swimmable. Often it's the smaller bodies of water, including many in agricultural areas, that are substandard. You would think that somebody is monitoring their quality, but in most cases, that's not so. Through GLOBE, we'll get information on many more streams, rivers and lakes.

Dr. Conklin: There are many water bodies around the world and each is unique. Students taking measurements is a wonderful way to gather information.

GLOBE: *Why do you need students to collect data? Why not have scientists or graduate students collect it?*

Dr. Bales: We're only a few people. Even if we went to twice as many places, we still wouldn't have much coverage.

GLOBE: *Are you concerned about things that are put in water by natural sources? By human sources? By both?*

Dr. Bales: Both. Impurities—and by impurities I don't mean anything that's necessarily bad, just anything other than $H_2 0$—can get in the water because rocks, dust and gases dissolve. Some impurities come from the atmosphere in rainfall or snowfall, which then enter streams and lakes. Some impurities come when humans dump waste into streams or lakes.

GLOBE: *You mentioned the exposure of water to rocks. Do rocks dissolve in water?*

Dr. Conklin: Yes, but very slowly. You can see the long-term-effect in old mountain ranges like the Appalachians. They're weathered and not so high.

GLOBE: *Why would bodies of water near agriculture be polluted?*

Dr. Bales: Growing crops involves the use of fertilizers and pesticides. You want the fertilizer and pesticides to stay in the field for the crops or to control pests. Unfortunately, rainwater and irrigation water carry some of those away to streams and lakes. Or into the ground water.

GLOBE: *Have students collected data for hydrologists before?*

Dr. Conklin: Students have collected data on lake and river systems, but not on GLOBE's scale.

The young Roger Bales spelunking at age 16.

GLOBE: *Tell us a little about yourselves. Where you were born? Where did you grow up?*

Dr. Bales: I was born in Lafayette, Indiana, and graduated from high school in Bloomington, Indiana. I got a degree from Purdue University in civil and environmental engineering. Then I took a master's degree in the same fields at the University of California in Berkeley.

Martha Conklin at age 15 on the Brighton sea shore.

Dr. Conklin: I was born in New Jersey, but soon my family moved to Illinois. Then we moved to Europe, which was quite a contrast. We lived in Holland for five years, where I became interested in science. Then I went to boarding school in England for two years, then came back and finished high school outside Boston.

GLOBE: *Did anyone discourage you from pursuing science because you were a woman?*

Dr. Conklin: No. I went to mainly all-girl schools, so there was never any question about whether girls could do science or math.

GLOBE: *When did you get into hydrology?*

Dr. Conklin: In graduate school. I became interested in what reactions occur in atmospheric droplets. So I studied water chemistry.

GLOBE: *What was happening?*

Dr. Conklin: We had just discovered that acid fogs occur, which are worse than acid rain. A rain droplet falls through the atmosphere quickly, picking up pollutants in the air, but fog droplets can be in the air for hours. They absorb more pollutants, and animals and people are more likely to breathe them.

GLOBE: *What do you do for fun and recreation?*

Dr. Bales: Play with our kids. We also have two Labrador retrievers and a cabin in the mountains above Tucson. I'm an avid hiker, mountain climber and skier, and we still do as much of that as we can, as well as ride our bicycles.

GLOBE: *Have you had an Archimedes-like "Eureka!" when you made a discovery on something you'd been working on?*

Dr. Conklin: I'm an experimentalist, not a theorist. I do laboratory experiments to try to understand processes that occur. I get excited when the data from lab experiments do not match what I think is going to happen. The fun thing is trying to figure out what actually is happening.

GLOBE: *As a scientist you find failed experiments beneficial?*

Dr. Conklin: Right. They are much more beneficial than if they turned out the way I thought they would. If it turns out that the results are different, that implies that my hypothesis is incorrect and I have to come up with a new one. That's the exciting thing about science.

GLOBE: *So science would be almost boring if the hypothesis was always correct?*

Dr. Conklin: Terribly boring!

GLOBE: *When you understand the mechanism of something, does that mean that you can predict what will happen?*

Dr. Bales: Exactly. Once we understand why things happen, we can say, "Well, if we have changes in the future, this is how the stream is going to respond." I'm in the business of predicting how streams or lakes respond to things like climate variability, global climate change or acid deposition.

GLOBE: *What is acid deposition?*

Dr. Bales: That's when rain or snow has a very low pH because it has dissolved strong acids from the atmosphere, many of which are produced by human activity. Acid rain plays havoc with a number of ecological niches.

GLOBE: *I think of acid as something that burns the skin. Yet acid rain* *doesn't feel different from any other kind of rain. What is it about acid rain that makes it acid rain?*

Dr. Bales: It's a strong acid that's mixed with water. It has a lower pH than natural rainfall. It's not as acidic as lemon juice or battery acid or something like that. But it could be as acidic as vinegar. In extreme cases, fog water could be as acidic as lemon juice. The main source of the acidity is the burning of fossil fuels such as gasoline, coal, and natural gas.

GLOBE: *And the emissions from the burning of these fossil fuels get into the atmosphere and interact with the water?*

Dr. Bales: Rainfall or snowfall scavenges these acids out of the atmosphere and they come back down to Earth. What goes up, comes down.

GLOBE: *What are the rewards of science? What do you get out of it?*

Dr. Bales: You feel you're contributing to an understanding of society's potential problems, and hopefully you're contributing to solutions. We examine the past, as in the case of Greenland, in order to get a clue to what the future may hold. How our environment may change as we burn more fossil fuels and change our atmosphere and waters.

Dr. Conklin: One of the most exciting things about science is that I keep getting new knowledge and in doing so, I also keep meeting new people. If I don't know something about a field, I'll find someone who does. So I also make new friends.

Dr. Bales: People need to make intelligent decisions about the Earth, even if they do so just as voters. So when I teach students about climate warming, about air pollution, about water pollution so they understand the Earth a little better, I find that very rewarding.

GLOBE: *Don't you already know enough? What drives you to want to know more?*

Dr. Conklin: Environmental systems have so many components to them that it's impossible for one person to ever know enough to understand them totally, but the more you know, the better your guesses are about what's happening to them.

GLOBE: *Did you have heroes when you were growing up?*

Dr. Conklin: One reason I'm interested in environmental science is that I always felt a need to make the world a better place. So if I have heroes it's the scientists who have tried to do that. Two are Linus Pauling, who got Nobel Prizes in both chemistry and peace, and Albert Einstein.

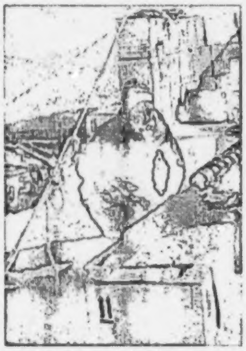
GLOBE: *Do you have international colleagues?*

Dr. Bales: Of course. We can't do everything ourselves and they can't do everything themselves, so we cooperate and share resources and data.

GLOBE: *As scientists, what are your days like? Do you have labs?*

Dr. Conklin: My average day now is working in my office, teaching, interacting with students, preparing classes, writing, analyzing my students' data, working on the computer a lot. I go into the lab to see how people are doing.

GLOBE: *It sounds like more and more scientific work is occurring on the computer. Is that true?*



Dr. Bales examining ice cores on the Greenland ice sheet

Dr. Conklin: Yes, collecting data is not enough. You have to understand it. So a lot of data analysis is done on the computer.

Dr. Bales: Most days, I spend a few hours preparing and teaching class. Then I spend an hour or two at the computer, corresponding with other scientists, reading and commenting on my students' work, or outlining things for my collaborators. Then I spend an hour or two with my graduate students. The rest gets taken up by meetings and university business.

GLOBE: *Have you any funny anecdotes about your work?*

Dr. Bales: I work a lot in mountain snowcaps because most of the water there falls as snow rather than rainfall, at least in the western U.S. And it seems ironic that I went to school all these years to get a Ph.D. only to go out and spend days digging holes in the snow with a shovel! When my mother sent me to college, she didn't tell me I'd be digging holes someday.

GLOBE: *So scientists can measure the introduction of impurities into the atmosphere by examining ice core samples that have been around for 100, 10,000 or even 100,000 years?*

Dr. Bales: Yes. In fact, I spent four weeks last summer on the Greenland ice sheet drilling ice cores. I slept in a tent on the ice for about 12 days.

GLOBE: *So you're surrounded by ice. Anything else?*

Dr. Bales: It's all white and blue. Snow and sky. Of course, the sun didn't set because we were way up north in the summer or spring. We were drilling ice cores and wanted to get done as soon as possible before a storm came in. You see the advent of the Industrial Revolution in the ice. A period of over three hundred years is very clear in the ice cores we did last summer. We also see forest fire signals in the ice core.

GLOBE: *How do you hope students will benefit from GLOBE?*

Dr. Conklin: I hope students learn how to determine the health of an environmental system. Society assumes that we can keep dumping pollutants and somehow the environment will take care of them. I hope that by checking their water systems and so on, students have some sense of whether they are healthy or polluted. I also hope they learn how to make good measurements.

GLOBE: Why should a student today consider entering your field?

Dr. Conklin: Water is one of our most important resources. Hydrology is a very good field that will become more important as clean water becomes scarcer.

Dr. Bales: Students want to do something that is not only interesting and gets them outdoors, but also contributes to a better environment and a better society. Our profession definitely does that because water is fundamental to all life on Earth.

GLOBE: Do you have any advice for students who want to get involved in Earth sciences or hydrology in particular?

Dr. Conklin: I hate to say it, but learn the basics. Math, physics, chemistry, biology. And learn how to ask questions, because those who ask the right questions will make the most important discoveries. And also learn how to write.

GLOBE: Why do you have to learn how to write?

Dr. Conklin: You could be brilliant, but if you can't communicate your results to other people, no one will know about them.

Dr. Bales: And learn as much about nature by direct experience as you can.

Introduction

The Big Picture

We do not just drink water; we are water. Water constitutes 50 to 90 percent of the weight of all living organisms. It is one of the most abundant and important substances on the Earth. Water sustains plant and animal life, plays a key role in the formation of weather, helps to shape the surface of the planet through erosion and other processes, and covers roughly 70% of the Earth's surface.

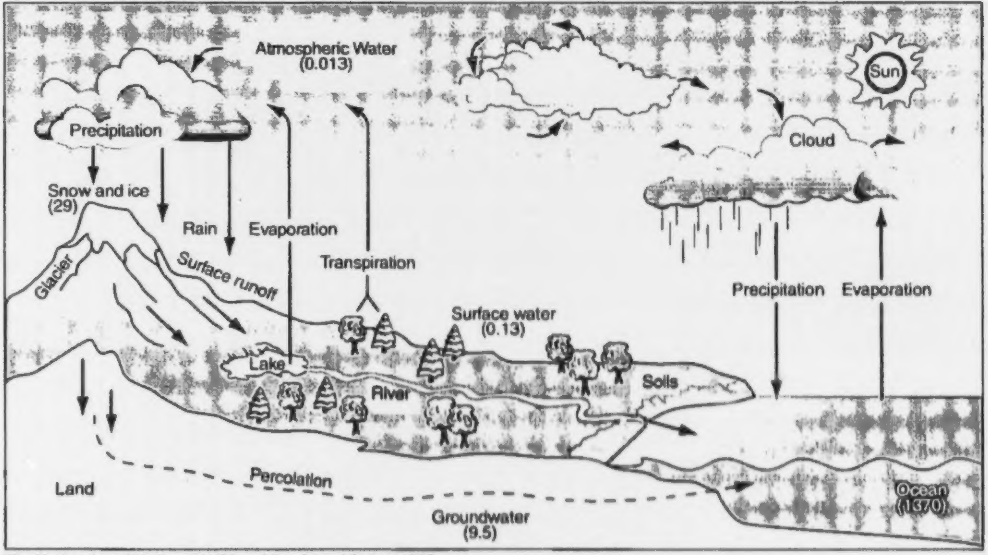
Water continually circulates between the Earth's surface and its atmosphere in what is called the hydrologic cycle. The hydrologic or water cycle, is one of the basic processes in nature. Responding to heat from the sun and other influences, water from the oceans, rivers, lakes, soils and vegetation evaporates into the air and becomes water vapor. The water vapor rises into the atmosphere, cools, and turns into liquid water or ice, forming clouds. When the water droplets or ice crystals get large enough, they fall back to the surface as rain or snow. Once on the ground, water does one of three things; some of it filters into the soil and is either absorbed by plants or percolates downward to groundwater reservoirs. Some runs off into streams and rivers and eventually into the oceans. Some evaporates.

The water in a lake, the snow on a mountain, the humid air or the drop of morning dew are all part of the same system. The total annual water loss from the surface of the planet equals the Earth's total annual precipitation. Changing any part of the system, such as the amount of vegetation in a region or land uses, affects the rest of the system.

Despite its abundance, we cannot use most of Earth's water. If we represent the Earth's water as 100 liters, 97 of them would be seawater. Most of the remaining three would be ice. Only about 3 mL out of the whole 100 liters would be water that we can consume; that water is pumped from the ground or taken from fresh water rivers and lakes.

Water participates in many important chemical reactions, and most substances are soluble in water. Due to its effectiveness as a solvent, truly

Figure HYD-I-1: Hydrologic Cycle - Numbers in parentheses are the reservoirs of available water in 10^3 Km^3.



After Mackenzie and Mackenzie 1995, and Graedel and Crutzen, 1993

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pure water rarely occurs in nature. Water carries many natural and human-introduced impurities as it travels through the hydrologic cycle. These impurities give each water its distinctive chemical makeup, or *quality*. Rain and snow capture small dust particles or *aerosols* from the air, and sunlight causes emissions from the burning of gasoline and other fossil fuels to react with water to form sulfuric and nitric acids. These pollutants return to Earth as *acid rain or snow*. The acids in the water slowly dissolve rocks, placing *dissolved* solids in water. Small but visible pieces of the rocks and soils also enter the water, resulting in *suspended* solids and making some waters turbid. When water percolates into the ground, it is in very close contact with rocks and more minerals dissolve into the water. These impurities dissolved or suspended in water determine its quality.

In this investigation, students will measure the following key indicators of water quality.

Transparency

Light, essential for growth of green plants, travels further in clear water than in either *turbid* water that contains suspended solids or colored water. Two methods that are commonly used to measure the transparency, or degree to which light penetrates into water, are the Secchi disk and turbidity tube. Secchi disk transparency was first measured in 1865 by Father Pietro Angelo Secchi, scientific advisor to the Pope. This simple and widely used measurement is the depth at which a 20-cm black and white disk lowered into water just disappears from view, and reappears again when raised. An alternate measure of transparency is obtained by pouring water into a tube with a pattern similar to that of a Secchi disk on the bottom and noting the depth of water in the tube when the pattern just disappears from view. The Secchi disk is used in deeper, still waters; the turbidity tube can be used with either still or flowing waters and can be used to measure shallow water sites or the surface layer of deep water sites.

Sunlight provides the energy for photosynthesis, the process by which plants grow by taking up carbon, nitrogen, phosphorus and other nutrients, and give off oxygen. Thus penetration of sunlight into a water body determines the depth to which algae and other plants can grow, and the relative amount of growth. Transparency decreases as color, suspended sediments, or algal abundance increases. Water is colored by the presence and action of some bacteria, phytoplankton, and other organisms, by chemicals leached from soil, and by decaying plant matter. Therefore, the amount of plant nutrients coming into a body of water from sources such as sewage treatment plants, septic tanks, fertilizer run-off, and wind and water born plant debris affects transparency. Suspended sediments often come from sources such as agriculture, construction, storm runoff and resuspension of bottom sediments.

Most natural waters have transparency ranging from 1 meter to a few meters. A low value, under 1 meter, would be expected in a highly productive body of water. A low value can be due as well to a high concentration of suspended solids. Extremely clear, unproductive lakes or coastal waters can have transparency up to 30 - 40 m as can the areas around coral reefs.

Water Temperature

Water temperature is largely determined by the amount of solar energy absorbed by the water and the surrounding soil and air. More solar heating leads to higher water temperatures. Water that has been used in manufacturing and discharged into a water body may also increase water temperature. Water evaporating from the surface can lower the temperature of the water but only for a very thin layer at the surface. We need to measure water temperature to understand the patterns of change over the year because the temperature of a water body strongly influences the amount and diversity of its aquatic life. Lakes that are relatively cold and have little plant life in winter bloom in the spring and summer when water temperatures rise and the nutrient-rich bottom waters mix with the upper waters. One also finds periods of mixing in the fall. Because of this mixing and the warmer water temperatures, the spring overturn is followed by a period of rapid growth of microscopic aquatic plants and animals. Many fish and other aquatic animals also spawn at this time of year when the temperatures rise and food is abundant. Shallow lakes are an exception to this cycle, as they mix throughout the year. One concern is that warm water can be fatal for sensitive species, such as trout or salmon, which require cold, oxygen-rich conditions.

Dissolved Oxygen

Water is a molecule made of two hydrogen atoms and one oxygen atom - hence, H_2O. However, mixed in with the water molecules of any body of water are molecules of oxygen gas (O_2) that have dissolved in the water. Dissolved oxygen is a natural impurity in water. Aquatic animals, such as fish and the zooplankton they feed on, do not breathe the oxygen in water molecules; they breathe the oxygen molecules dissolved throughout the water. Without sufficient levels of dissolved oxygen in the water, aquatic life suffocates. Dissolved oxygen levels below 3 mg/L are stressful to most aquatic organisms.

In the atmosphere, roughly one out of every five molecules is oxygen; in water, about one to ten molecules in every million molecules are oxygen. Vigorous mixing of air and water, such as in turbulent streams, increases the amount of oxygen dissolved in water. So does photosynthesis by aquatic plants. Oxygen is consumed by fish, zooplankton, and the bacteria that decompose organic materials. Organic materials such as dead plant and animal matter enter streams naturally in water draining from forests and grass or crop lands. Another source of organic matter is outfalls from sewage treatment plants. Whatever the source, we tend to find low dissolved oxygen levels, well under half the saturated value, in slow-moving streams near sources of organic matter. In addition, warm water holds less oxygen than cold water, so critical periods for fish and zooplankton tend to occur in summer. For example, at 25° C, dissolved oxygen solubility is 8.3 mg/L, whereas at 4° C the solubility is 13.1 mg/L.

pH

pH is a measure of the acid content of water. The pH of a water influences most of its chemical processes. Pure water with no impurities (and not in contact with air) has a pH of 7. Water with impurities will have a pH of 7 when its acid and base content are exactly equal and balance each other out. At pH values below 7 we have excess acid, and at pH levels above 7 we have excess base in the water.

The pH scale is different from the concentration scale we use for other impurities. It is logarithmic, which means that a one-unit change in pH represents a factor of ten change in the acid content of the water. Thus water with a pH of 3 has ten times the acid content of water with a pH of 4, which in turn has ten times the acid content of water with a pH of 5.

Natural, unpolluted rain has a pH between 5 and 6, so even rain water from the least polluted place on Earth has some natural acidity. This natural acidity is the result of carbon dioxide from the air dissolving in the rain drops. Distilled water which is in equilibrium with the air will have this same pH. The most acidic rain has a pH of about 4, though urban fogs with pH of less than 2 have been measured. Most lakes and streams have pH's in the range of 6.5 to 8.5. One can find waters that are naturally more acidic in areas with certain types of minerals in the soil, (e.g., sulfides). Mining activity can also release acid-causing minerals to a stream. Naturally basic waters are found typically in areas where the soil contains minerals such as calcite or limestone.

The pH of a water body has a strong influence on what can live in it. Salamanders, frogs and other amphibian life are particularly sensitive to low pH. Most insects, amphibians, and fish are absent in water bodies with pH below 4.

Electrical Conductivity

Pure water is a poor conductor of electricity. It is the impurities in water, such as dissolved salts, that enable water to conduct electricity. Since we lack the time or money to analyze water for each substance, we have found a good indicator of the total level of impurities in fresh water to be its electrical conductivity - how well a water passes electrical current. The more impurities in water, the greater its electrical conductivity.

For most agricultural and municipal uses, we want water that has a total dissolved solids content well below 1000-1200 parts impurity per million parts water by weight (ppm), or an electrical conductivity (ability to pass electrical current) below about 1500-1800 microSiemens/cm (Note that 1 ppm = 1mg/L). Above these levels, one can expect damage to sensitive crops. For household use, we prefer water with a total dissolved-solids content below about 500 ppm, or below a conductivity of about 750 microSiemens/cm. The residues left on "clean" dishes just out of the automatic dishwasher are a product of dissolved solids in water. Manufacturing, especially of electronics, requires impurity-free water. Pure, alpine snow from remote areas has a conductivity of about 5-30 microSiemens/cm.

Salinity

The sea is salty; it has a much higher dissolved solids content than do fresh waters. Salinity is a measure of that saltiness and is expressed in parts impurity per thousand parts water. The average salinity of the Earth's oceans is 35 parts per thousand (35 ppt). Sodium and chloride, the components of common table salt (NaCl), contribute the most to the salinity. Since the proportion of chloride in seawater changes little from place to place we can also measure the chloride content, referred to as chlorinity, to estimate the total salinity. In bays and estuaries we can find a wide range of salinity values, since these are the regions where freshwaters and seawater mix. The salinity of these *brackish* waters is between that of freshwater, which averages 0.5 ppt, and seawater.

Every continent on Earth also has inland lakes that are saline. Some of the more prominent examples are the Caspian Sea in Central Asia, the Great Salt Lake in North America, and several lakes in the Great Rift Valley of East Africa. Some of these are even more saline than seawater. Waters acquire salinity because rivers carry salts that originated from the weathering or dissolving of continental rocks. When water evaporates the salts stay behind, resulting in a buildup of dissolved material. At some point the water becomes *saturated* with solids, they precipitate out as solids, and they settle out of the water. Whereas the ocean's salinity changes slowly, over many millennia, the salinity of inland waters can change more quickly when rainfall or snowmelt patterns change.

The salt content of a water body is one of the main factors determining what organisms will be found there. Thus fresh waters and saline waters are inhabited by quite different organisms. Plants and animals that live in or use freshwater (below 1 ppt) generally have a salt content inside their cells that is greater than the water they inhabit or use. They tend to give off salts as waste products. Saltwater plants and animals have a salt content equal to or less than the salinity of the surrounding water, and thus have different mechanisms for maintaining their salt balance. In brackish waters (salinity values of 1 - 10 ppt) we find plants and animals that can tolerate changes in salinity.

Alkalinity

Alkalinity is the measure of a water's resistance to the lowering of pH when acids are added to the water. Acid additions generally come from rain or snow, though soil sources are also important in some areas. Alkalinity is generated as water dissolves rocks containing calcium carbonate such as calcite and limestone. When a lake or stream has too little alkalinity, typically below about 100 mg/L, a large influx of acids from a big rainfall or rapid snowmelt event could (at least temporarily) consume all of the alkalinity and thus drop the pH of the water to levels harmful for amphibians, fish or zooplankton. We find lakes and streams in areas with little soil, such as in mountainous areas, are often low in alkalinity. These water bodies can be particularly sensitive in the spring during periods of rapid snowmelt. Because pollutants tend to wash out of a snowpack during the first part of snowmelt, we often encounter a higher influx of acidic pollutants in spring, which is also a critical time for the growth of aquatic life.

Nitrate

Plants in both fresh and saline waters require three major nutrients for growth: carbon, nitrogen and phosphorus. In fact, most plants tend to use these three nutrients in the same proportion, and cannot grow if one is in short supply. Carbon is relatively abundant in the air as carbon dioxide which dissolves in water, so a lack of either nitrogen or phosphorus generally limits the growth of aquatic plants. In some cases trace nutrients such as iron can also be limiting, as can sunlight. Nitrogen exists in water bodies in numerous forms: dissolved molecular nitrogen (N_2), organic compounds, ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-). Of these, nitrate is usually the most important. Nitrite is usually only present in suboxic waters (low dissolved oxygen levels). The nitrate form of nitrogen found in natural waters comes naturally from the atmosphere in rain, snow, fog or dry deposition, or from the decay of organic material in soil and sediments. It can also come from agricultural runoff; farmers add nitrogen fertilizer to crops, some of which drains out of the soil when it rains.

When an excess amount of a limiting nutrient such as nitrogen is added to a lake or stream the water becomes *enriched* and further growth of algae and other plants ensues. We call this process of enriching the water *eutrophication*. The resulting excess plant growth can cause taste and odor problems in lakes used for drinking water, can cause nuisance problems for users of the water body, or can adversely affect fish and other aquatic animals. Concerns about excess nitrogen or phosphorus in lakes and coastal waters are often associated with sewage discharges. Concentrations of nitrate should always be expressed as elemental nitrogen. Thus nitrate is expressed as nitrate nitrogen (NO_3–N) in milligrams per liter (that is, 14 g of nitrogen per mole of NO_3^-) and never as NO_3 (that is 62 g per mole NO_3^-). Most natural waters have nitrate levels under 1 mg/L nitrate nitrogen, but concentrations up to 10 mg/L nitrate nitrogen are found in some areas.

The Importance of Measurements

What is the condition of the Earth's many surface waters - the streams, rivers, lakes, and coastal waters? How do these conditions vary over the year? Are these conditions changing from year to year? Through the GLOBE *Hydrology Investigation*, your students, together with students at other GLOBE schools, address these questions by continuous, widespread monitoring of natural waters. Our knowledge of national and global trends in water quality is based on sampling at a very few representative sites. This sampling has generally been done only a few times. For example, our information on many lakes is based on sampling done only once or twice more than ten years ago. Before we can assess changes, we need reliable information on current conditions. When changes are already underway, comparison of affected and unaffected areas can help us understand what is happening.

Measures of dissolved oxygen and pH directly indicate how hospitable a body of water is to aquatic life. Again, it is interesting to both follow the annual cycle of dissolved oxygen, alkalinity and pH, and to make comparisons between different water bodies. We can ask such questions as: are dissolved oxygen levels always at the maximum allowed by the temperature of the water, or are they depressed during part of the year? If they are low, we want to know the cause. We can see if pH becomes depressed right after a rain or when there is a lot of snowmelt running off into the lake or stream. If we do find a depression in pH, we would expect that this water had a low level of alkalinity. In fact, we should expect that waters with a low alkalinity would have a depression in pH following rainfall or snowmelt. But we must make the measurement to confirm whether or not that really happens.

Students should make this suite of GLOBE measurements with at least two societal goals in mind. First, we want to develop a better understanding of our local land and water resources. This knowledge can help us make more intelligent decisions about how we use, manage and enjoy the resources. Second, we want to assess the extent to which human activities are affecting the quality of our water and thus affecting how we will be able to use it in the future. In most countries current measurement programs cover only a few water bodies at a few times during the year. We hope the measurements you make in the GLOBE program will help fill this gap and improve our understanding of the health of Earth's natural waters.

Preparing for the Field

Overview

Students will take samples of water from a selected body of water, process the samples to determine their composition, and analyze the data to come to better understand the quality of water and its impact on their environment.

Table HYD-I-1 lists the recommended protocols for the three levels of GLOBE. Teachers should use their own judgment as to which protocols are consistent with their students' abilities. Please note that the more advanced protocols involve special safety considerations.

Table HYD-I-1: Hydrology Measurement Levels

Level	Measurements
Beginning	transparency temperature pH (paper) conductivity or salinity
Intermediate/ Advanced	transparency temperature dissolved oxygen pH (pen or meter) conductivity or salinity alkalinity nitrate

Measurement Schedule

Measurements must be made one day per week, at the same time of day and on the same day of the week. Weekly measurements are particularly important during those times of the year when hydrology sites are undergoing rapid change. Samples can be collected for all protocols at each site visit.

Site Selection (in order of preference)

1. Stream or river
2. Lake, reservoir, bay or ocean
3. Pond
4. An irrigation ditch or other water body if one of the above is not accessible or available within your GLOBE Study Site.

Student Groups

Measurements should be taken by groups of 2-3 students. Tasks within a group include collecting samples, processing samples, and recording data. It is very useful to have multiple groups testing for each parameter (for example, two groups measure dissolved oxygen). This allows more students to get involved and builds in some quality control. Groups of students conducting the same test should look at each other's results to determine if the data are similar. If there are different results for the same sample, students should check the procedures and redo the test to determine what caused the difference. Data quality control should be an important part of the science and the learning experience.

Overview of Educational Activities

When the protocols for conducting each measurement are combined with the *Learning Activities*, a comprehensive program for understanding the chemistry of water bodies is established. There may be a temptation to have students merely take measurements and enter the data on the GLOBE data pages. However, gaining knowledge about science content, processes, and critical thinking skills are our educational goals. The *Learning Activities* will assist you in providing the context for the *Protocols*.

Student Learning Goals

This investigation develops students' understanding of the importance, unique properties and content of water. Through applications of water analyses, students come to understand water chemistry and how it is important in understanding the health of aquatic environments.

Upon completing all of the activities in this investigation, students should know and understand the following concepts and skills.

Concepts

Water chemistry is an important aspect of habitat requirements
Temperature can affect other water chemistry factors
Water chemistry affects species diversity
Instruments can enhance what your senses tell you about what is in water
Data are used to pose and answer questions
Graphs and maps are valuable tools for visualizing data
Accuracy and precision are important when taking measurements
The soil stores water, and its water content is related to the growth of vegetation
Where rainfall goes depends on your site characteristics
Higher temperatures and longer periods of sunshine increase evapotranspiration
Water flows can change over time
Water balance can be modeled using temperature, precipitation, and latitude data

Skills

Making observations
Applying field sampling techniques
Calibrating scientific equipment
Following directions in methods and test kits
Recording and *reporting* data accurately
Reading a scale
Communicating orally
Communicating in writing
Asking Questions
Forming and *testing* hypotheses
Designing experiments, tools, and models
Using water quality measurement equipment
Using tools to enhance the senses
Creating and *reading* graphs
Calculating averages
Making comparisons over space and time
Analyzing data for trends and differences
Using the GLOBE database

Student Assessment

Individual assessment of students' roles in this project and peer grading can be used, and the total study incorporated in students' portfolios. GLOBE Science Notebooks can be regularly assessed to chart the students' progress in understanding key science concepts, processes, and skills. They also can be the foundation for the development and assessment of communications skills, both written and oral. Reports and presentations should be designed using the material in the GLOBE Science Notebooks.

In addition to entering the data into the GLOBE Student Data Server, at levels where it is educationally appropriate, students should analyze their data and write reports. Have students write about the parameters they tested and compile all the individual reports into a complete study of the site. Submit the study to local and state agencies that govern water and water quality.

References

T.E. Graedel and P.J. Crutzen (1993) *Atmospheric Change: An Earth System Perspective.* W.H. Freeman and Company, New York

F.T. Mackenzie and J.A. Mackenzie (1995) *Our Changing Planet: An Introduction to Earth System Science and Global Environmental Change.* Prentice Hall, New Jersey.

Protocols

How to Perform Your Hydrology Investigation

Collecting the Water Sample

Water Transparency Protocol

Students will first measure water transparency at their undisturbed sampling site.

Water Temperature Protocol

Immediately after collecting their water sample or *in situ*, students will measure the temperature of the water.

Dissolved Oxygen Protocol

Students will measure the dissolved oxygen in their water sample or *in situ*.

pH Protocol

Students will measure the pH of their water sample. Method one uses pH indicator paper, and method two uses pH pens or pH meters.

Electrical Conductivity Protocol

Students will measure the electrical conductivity of their fresh water sample.

Salinity Protocol

Students will measure the salinity of their salty or brackish water sample using a hydrometer.

Optional Salinity Titration Protocol

Intermediate or advanced students will measure the salinity of their salty or brackish water sample using a chlorinity titration.

Alkalinity Protocol

Students will measure the alkalinity of their water sample.

Nitrate Protocol

Students will measure the nitrate-nitrogen content of their water sample.

How to Perform Your Hydrology Investigation

Preparing For Your Hydrology Measurements

Selecting the Hydrology Study Site

Ideally, the Hydrology Study Site will be within a watershed that is a prominent feature in the 15 km x 15 km GLOBE Study Site. Within this watershed, select a specific site where the hydrology measurements (water temperature, transparency, pH, dissolved oxygen, alkalinity, electrical conductivity or salinity, and nitrate) will be taken. If there is a water body of special interest within your watershed, by all means choose that. Otherwise, the water bodies in order of preference are:

1. Stream or river
2. Lake, reservoir, bay, or the ocean
3. Pond

An irrigation ditch or other water body may be used if one of the above is not accessible or available within your GLOBE study site.

You should collect all water samples from the same place at the hydrology site each time. This is called the sampling site.

If the site is a moving body of water, like a stream or a river (*lotic*), locate your sampling site at a riffle area (a place where the water is moving but not too fast) as opposed to still water or rapids. If the site is a still body of water, like a lake or reservoir (*lentic*), find a sampling site near the outlet area or along the middle of the water body, but avoid taking samples near an inlet. A bridge or a pier are good choices. If your brackish or salty water body is affected by tides, you will need to know the times of high and low tide at a location as close as possible to your study site.

Site Description

Once you have selected your hydrology site, be sure to identify the coordinates of this site with the GPS receiver. Enter the location plus other site description information requested on the Hydrology Investigation Site Selection Data Entry Sheet. For the salinity protocols, you will need to know the latitude and longitude of the location for which you will report the times of high and low tide. You can measure these using a GPS receiver and following the *GPS Protocol* or obtain them from those who provide the high and low tide information.

Frequency

Collect all water-chemistry measurements at roughly the same time each day, on a weekly basis. If your sampling site freezes over in winter or runs dry, be sure to enter this information on the data sheet each week until you again have free-flowing surface water to measure.

Note: Certain times of the year provide more exciting measurements. When runoff is occurring on a river, the increased flow and sediment will dramatically change water-chemistry measurements. Just after ice melts off a lake is also a dramatic time because various layers of water in the lake are mixing with layers near or at the bottom of the lake. Often layers near the bottom end up on top near the surface, thus adding surprising changes to your measurement results. Be observant of seasonal and monthly changes.

Quality Assurance and Quality Control

A quality assurance and quality control (QA/QC) plan is necessary to ensure that test results are as accurate and precise as possible. Accuracy refers to how close a measurement is to true value. Precision means the ability to obtain consistent results. Reliability in both accuracy and precision is achieved by:

- Collecting the water sample as directed
- Performing tests immediately after collecting the water sample
- Careful calibration, use and maintenance of testing equipment

- Following the specific directions of a protocol exactly as described
- Repeating measurements to check their accuracy and to understand any sources of error
- Minimizing contamination of stock chemicals and testing equipment
- Checking to be sure the numbers submitted to the GLOBE Student Data Server are the same as those recorded on the Hydrology Investigation Data Work Sheet.

Calibration

Calibration is a procedure to check the accuracy of testing equipment. For example, to ensure that the pH instruments are functioning properly, a solution of known value is tested. Calibration procedures vary among the measurements and are detailed in each protocol. Certain calibrations must be done the same day as the field measurements. Some calibration procedures may be done in the classroom just before taking the equipment out into the field. However, in some cases, it may be necessary to check the calibration again in the field by doing a field measurement of a known value solution. See *pH* and *Electrical Conductivity Protocols*.

Promptness and Sequence When Making Measurements

Testing for transparency, temperature, and dissolved oxygen should be done on site (*in situ*) immediately after obtaining the water sample. Do not let the bucket of water sit for more than a half hour before taking measurements. Take a new sample if this happens. If unavoidable, samples may be bottled (see Bottling Technique in collecting your water sample) and tested in the classroom. However, we strongly recommend that all testing be done at the sampling site. We do not recommend doing the dissolved oxygen test in the classroom since the analysis should be done within 30 minutes of collection. Measurement of pH and nitrate (within 2 hours), alkalinity, electrical conductivity or salinity (within 24 hours) may be done later in the classroom if necessary.

Important: The sequence in which the measurements are performed is important. Transparency measurements should be taken first, followed immediately by the water temperature measurements and the dissolved oxygen test, then pH, electrical conductivity or salinity, alkalinity, and nitrate.

Important: Dissolved oxygen measurements have limited value unless the temperature of the water is known. Measure dissolved oxygen only if you measure water temperature. If your site is a salty or brackish water you also must measure salinity in order to interpret the dissolved oxygen measurements.

Repeated Measurements

Divide your class into at least two groups for each measurement. Once one group has finished their measurement, have them hand the equipment to the second group. Both groups use the same bucket of water for the measurement.

If the values found by the two groups differ significantly, the measurement should be repeated by a third group and perhaps repeated by the first two groups. The following are the maximum acceptable differences between measured values.

Measurement	Maximum Difference
Transparency	1.0 cm
Water Temperature	0.5° C
Dissolved Oxygen	0.4 mg/L (La Motte kit) 1.0 mg/L (Hach kit)
pH (using paper)	1.0 pH unit
pH (using pen or meter)	0.2 pH unit
Conductivity	2% of full scale (40 µS/cm)
Salinity (hydrometer)	0.4 parts per thousand
Salinity (titration kit)	0.4 parts per thousand
Alkalinity	4 mg/L as $CaCO_3$ (La Motte Kit) 1 drop (Hach Kit): 17 mg/L as $CaCO_3$ (high range) 6.8 mg/L as $CaCO_3$ (low range)
Nitrate	1.0 mg/L

Each group should use its own Hydrology Investigation Data Work Sheet. The value submitted to the GLOBE Student Data Server should be an average of all values obtained that meet the above criteria. Discard values that fall far outside the maximum differences. Note that for water transparency, all values should be submitted to the GLOBE Student Data Server.

Disposal of Liquid Waste

After tests have been conducted, all solutions (except for the nitrate analysis and salinity titration) and liquids should be collected in a wide-mouthed screw top plastic waste container and disposed of in a school sink or utility sink, and flushed with excess water. Or, they should be disposed of according to your local school district's safety procedure guidelines. The wastes from the nitrate analysis and the salinity titration (which typically contain cadmium and chromate, respectively) should be disposed of according to your local school district's safety procedure guidelines.

Collecting the Water Sample

Materials and Tools

4-L bucket with a strong rope attached securely to the handle
Paper towels
500 mL-polyethylene sample bottles
GLOBE Science Notebooks, pens, Data Work Sheets
Latex gloves (recommended)

If students can SAFELY reach the water body (within arms' reach), water temperature, pH, dissolved oxygen, and electrical conductivity measurements can be taken *in situ* directly at the water's edge. However, the measurements of alkalinity, salinity, and nitrate require a sample to be taken with a bucket. The water samples should be tested immediately after they are obtained. If unavoidable, samples may be bottled and tested for pH, alkalinity and salinity or electrical conductivity after returning to the classroom. The oxygen in the water must be stabilized by doing the initial steps of the dissolved oxygen protocol before the sample can be transported. Use the following techniques to obtain water samples for immediate testing and to bottle samples for testing in the classroom.

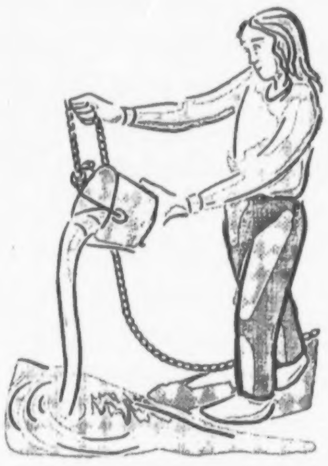
A sample of surface water can be used with the turbidity tube. The Secchi disk measurement is only appropriate for deeper water and measurements are generally taken from a bridge or pier, away from the water's edge.

Sampling Technique

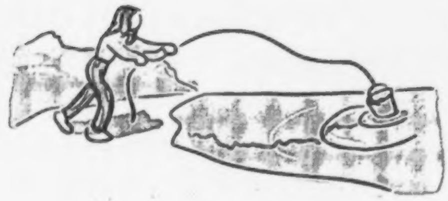
1. Holding onto the rope, lower the bucket into the water and allow it to fill partially with water. If the bucket sits on its end, its lip is not lowering enough to allow water into it; jostle it with the rope. Once some water enters the bucket, retrieve the bucket and swirl the water around to clean out the bucket. Discard this water and repeat the procedure once more. Do not use distilled water to rinse the bucket as this will change the sampling results. Likewise never let the sampling bucket be used for cleaning or other purposes since this will also affect the sampling results.

   If your sampling site is a stream, throw the bucket out to a well-mixed area, a little distance from the shore. Ideally, the water should be flowing at least slightly. If you are sampling from a fast-moving stream, grip the bucket rope tightly so the force of the water's flow does not take your bucket with it.

   If you are sampling from a lake, bay, or the ocean, take samples from the shore and throw the bucket out as far as possible to take your sample. You should always take a sample from the top surface water. Do not let the bucket fill up and



Rinsing the water bucket.



Casting the bucket.

sink. Also be careful not to stir up bottom sediment.

2. To obtain a sample, allow the bucket to fill to about 2/3 to 3/4 full. Then hoist the bucket out of the water.

Bottling Technique

While the preferred procedure is to do all testing at the Hydrology Study Site, measurements of pH, alkalinity, nitrate and electrical conductivity or salinity can be done in the classroom. The dissolved oxygen protocol can be completed in the classroom after the dissolved oxygen has been stabilized in the field.

Use the following procedure to bottle sample water and transport it to the classroom for all but temperature, dissolved oxygen and transparency measurements.

1. Label a 500-mL polyethylene bottle with your school's name, the teacher's name, the site name, the date and time of collection.
2. Rinse the bottle and cap with sample water.
3. Fill the bottle with sample water until the water forms a dome shape at the top of the bottle so that, when the cap is put on, no air is trapped inside.
4. Seal the cap of the bottle with masking tape.
   Note: Tape serves as a label, and an indicator of whether the bottle has been opened. Tape should NOT be in contact with the water sample itself.
5. Store these samples in a refrigerator at about 4° C until they can be tested (within 2 hours for pH and nitrate and within 24 hours for alkalinity and salinity or electrical conductivity).
6. Once the seal is broken, do the pH test first, then the tests for salinity or electrical conductivity, alkalinity, and nitrate. Ideally, once opened, all the measurements should be performed during the same lab session.

Safety

- Consult the Material Science Data Sheets (MSDS) that come with kits and buffers. Also consult your local school district's safety procedure guidelines.
- In any cases where using kits with chemicals, latex gloves and safety goggles are recommended.

Water Transparency Protocol

Purpose

To determine water transparency using a Secchi disk (still, deep waters) or turbidity tube (flowing or shallow waters)

Overview

The Secchi disk is a widely used measure of the transparency of water to light. The Secchi disk transparency depends on the amounts of suspended and colored material in the water, material that comes from either sediment washed into a water body or biological activity in the water body. A turbidity tube is used to measure transparency of flowing waters, or where use of a Secchi disk is impractical.

Time

10-15 minutes

Level

All

Frequency

Weekly

Key Concepts

- Determining water transparency using a Secchi disk or turbidity tube
- Light scattering
- Suspended particles
- Light absorption
- Water color
- Productivity

Skills

- *Using* a Secchi disk or turbidity tube
- *Designing* measurement strategies
- *Recording* data
- *Interpreting* results

Materials and Tools

Secchi disk:

- 5 m length of rope (or longer or shorter, depending on depth of the water at the site)
- Latex enamel spray paint: black and white
- 2.5-3 cm diameter by 15 cm long steel pipe
- Drill
- Circular piece of wood 2.5 cm thick and 20 cm diameter
- 2 hook screws
- 15 cm length of string
- Small bottle of wood glue or super glue
- Waterproof markers (red, blue, and black)
- Meter stick

Turbidity tube:

- Clear plastic tube, approx. 1 m long (depending on transparency of water at your site) and 4.5 cm diameter (e.g. Clear plastic fluorescent light casing, found at hardware or lumber stores)
- White cap that fits securely on the bottom of the tube (a cap to a PVC pipe fits nicely)
- Black permanent marker
- Meter stick

Preparation

If a Secchi disk is not ordered, one must be made. To make one, follow the directions in Design and Learning Approach.

If a turbidity tube will be used, it must be made before going to the study site.

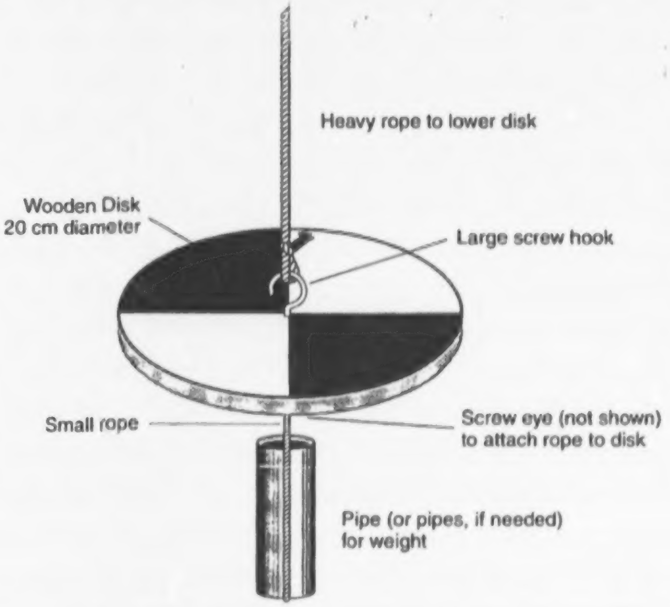
Prerequisites

A brief discussion of how the Secchi disk or turbidity tube can be used in the indication of water transparency is necessary before students make their first measurement.

To make a Secchi disk:

1. Divide top of wooden disk into four quadrants drawing lightly in pencil (draw 2 lines crossing at a 90 degree angle).
2. Paint two opposite quadrants in black and the other two in white.
3. Screw a hook screw into the top center and bottom center of the disk. Then tie the 5-m (or longer) rope through the hook screw in the top of the disk.
4. Tie a short piece of rope through the hook screw on the bottom of the disk and string it though the pipe. Tie a large knot at the bottom of the pipe so that it does not fall off when hanging vertically underneath the disk.
5. Hold the rope attached to the top of the disk and use the meter stick and measure distance from the disk. Mark rope with a black waterproof marker every 10 cm. Mark every 50 cm up from the disk with a blue marker and every meter with a red marker. Now you are ready to make a measurement.

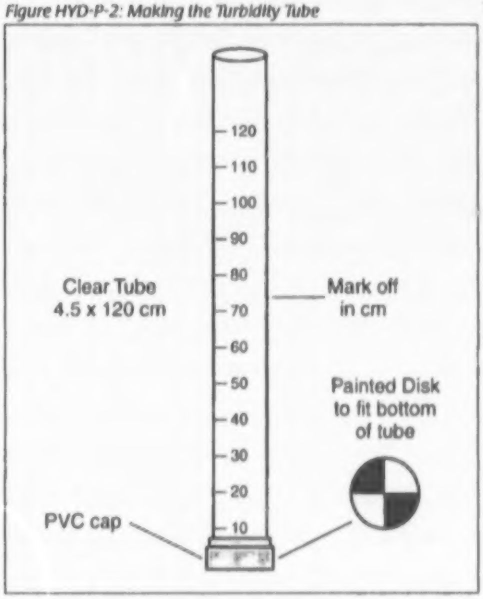
Figure HYD-P-1: Making a Secchi Disk


Heavy rope to lower disk
Wooden Disk
20 cm diameter
Large screw hook
Small rope
Screw eye (not shown)
to attach rope to disk
Pipe (or pipes, if needed)
for weight

To make a turbidity tube:

1. Put PVC cap over one end of clear tube. Cap should fit tightly so water cannot leak out.
2. Cut a disk from wood, plastic, or cardboard the same size as the tube diameter.
3. Divide the disk into fourths. Paint alternating quadrants black and white. Seal the disk by laminating or painting with varnish to make it waterproof.
4. Glue the disk in the bottom of the tube, painted side facing up (toward the open end of the tube).
5. Use a marker and meter stick to make a scale on the side of the tube, beginning at the top of the disk with 0 cm.

Figure HYD-P-2: Making the Turbidity Tube



How to Measure Transparency

Make sure that Secchi disk and turbidity tube measurements are made in the shade with the sun to your back to make an accurate and reproducible reading. If there is no shade available, use an umbrella or a large piece of cardboard to shade the particular area where the measurement is being made. For the turbidity tube the shadow of the observer should be adequate.

Different individuals may see the Secchi disk or the bottom of the turbidity tube disappear at different water depths. For this reason, whenever possible the transparency observation should be made by three different students and each of their observations submitted to the GLOBE Student Data Server.

Secchi disk

1. Lower the disk slowly into the water until it just disappears. If possible, grab the rope at the surface of the water and mark this point on the rope (e.g. use a clothes pin). If it is not possible to mark the rope at the water surface, mark the rope a known distance above the water.
2. Then raise the Secchi disk until it just reappears into view. Grab the line at the surface of the water when the Secchi disk reappears and mark this point (or some known distance above the water). The rope should now be marked at two points. There should only be a few centimeters difference between these two points.
3. Record both depths on your Hydrology Investigation Data Work Sheet to the nearest 1 cm.
4. If the two depths differ by more than 10 cm, repeat the measurement, recording the new depths on your Hydrology Investigation Data Work Sheet.
5. Using the *Cloud Cover Protocol*, determine the cloud cover. Determine the distances between where each observer marked the rope and the water surface. Record both on your Hydrology Investigation Data Work Sheet. If the rope was marked at the water surface enter 0.

6. Submit your depths along with the cloud cover and distance from the mark to the water surface to the GLOBE Student Data Server. **Note**: Enter data for each observer, not the average of the different observations.

Note: If the Secchi Disk reaches the bottom of your study site and you can still see it, simply record the depth to the bottom by referring to the point where the rope is at the water surface and put a greater than (>) symbol in front of the measurement both on your data work sheet and when you submit the value to the GLOBE Student Data Server.

Turbidity tube

1. Pour sample water into the tube until the image at the bottom of the tube is no longer visible when looking directly through the water column at the image. Rotate the tube while looking down at the image to see if the black and white areas of the decal are distinguishable.
2. Record this depth of water on your Hydrology Investigation Data Work Sheet to the nearest 1 cm.
3. Submit your depth to the GLOBE Student Data Server. Enter data for each observer, not the average of the different observations.

Note: If you can still see the image on the bottom of the tube after filling it, simply record the depth as > the depth of the tube.

Water Temperature Protocol

Purpose

To measure the temperature of the water sample

Overview

The temperature of the water sample is needed for the dissolved oxygen and pH measurements, and for studies of global hydrology questions.

Time

5 minutes after the thermometer has been calibrated

Level

All

Frequency

Weekly

Calibration every three months

Key Concepts

Temperature, temperature measurement
Heat, heat transfer, conduction
Accuracy
Precision

Skills

Using a thermometer properly
Reading a scale
Recording data

Materials and Tools

Alcohol-filled thermometer
A clock or watch
Enough string to lower the thermometer into the water
Rubber band
Data sheets

Preparation

Bring the tools and materials to the Hydrology Study Site.

Prerequisites

None

Calibration and Quality Control

This measurement takes only a few minutes to complete. The main concern is to allow sufficient time for the thermometer to equilibrate to the temperature of the water perhaps three to five minutes.

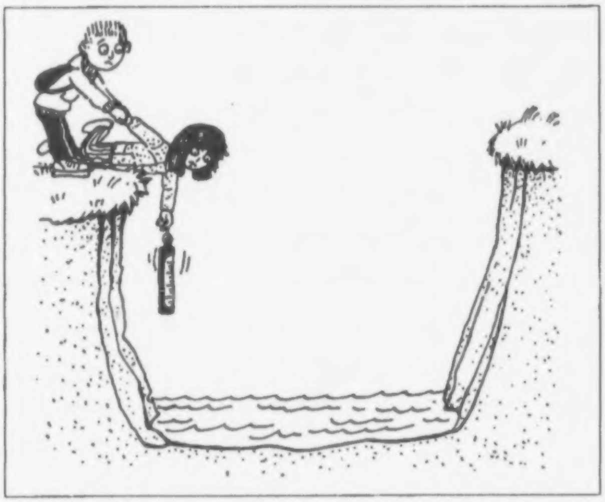
Your organic liquid-filled thermometer should be calibrated at least every three months as well as before its first use. Calibrate it following the instructions in the *Atmosphere Investigation Maximum, Minimum, and Current Temperatures Protocol.*

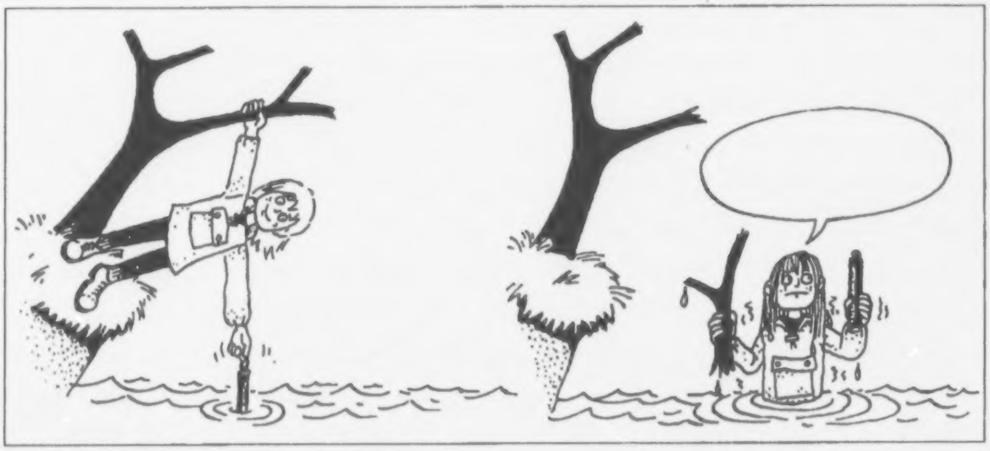
How to Measure Water Temperature

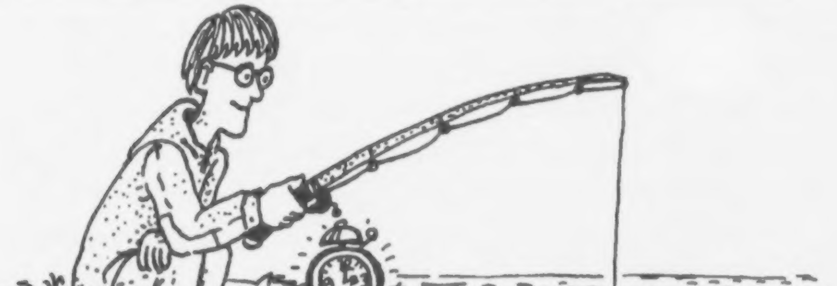
1. Tie one end of a piece of string securely to the end of the thermometer and the other end to a rubber band. Slip the rubber band around the wrist so that the thermometer is not lost if it is accidentally dropped in the water.
2. Hold the end of the thermometer (opposite the bulb) and shake it several times to remove any air in the enclosed liquid. Note the temperature reading.
3. Immerse the thermometer to a depth of 10 cm in the sample water for three to five minutes.
4. Raise the thermometer only as much as is necessary to read the temperature. Quickly note the temperature reading. If

the air temperature is significantly different from the water temperature or it is a windy day, the thermometer reading may change rapidly after it is removed from the water; try to take the reading while the bulb of the thermometer is still in the water. Lower the thermometer for another minute or until it stabilizes. Read it again. If the temperature is unchanged, proceed to Step 5.

5. Record this temperature along with the date and time on the Hydrology Investigation Data Work Sheet.
6. Take the average of the temperatures measured by the student groups. If all measured values are within 1.0° C of the average, submit the average value to the GLOBE Student Data Server. Otherwise, repeat the measurement.







Source: Jan Smolík, 1996, TEREZA, Association for Environmental Education, Czech Republic

Dissolved Oxygen (DO) Protocol

Purpose

To measure the amount of oxygen dissolved in the water sample

Overview

Dissolved oxygen is closely related to survival of plant and animal life in all bodies of water. It is affected by natural processes and by human activities.

Time

15 minutes for calibration
15 minutes in the field

Level

Intermediate and Advanced

Frequency

Weekly

Calibration every six months

Key Concepts

- Dissolved oxygen
- Comparing with a standard
- Accuracy, Precision

Skills

Using the dissolved oxygen test kit properly
Recording data

Materials and Tools

- Dissolved Oxygen Kit (See *Toolkit*)
  - Safety note: This kit contains hazardous chemicals
- Distilled water
- 250-mL polyethylene bottle with top
- Thermometer
- Data Work Sheets
- Latex gloves/safety goggles

Preparation

Practice sample preparation and preservation procedure given in this protocol.

Bring the tools and materials to the Hydrology Study Site.

Prerequisites

None

Calibration and Quality Control

Calibration should be performed every six months to verify your technique and the integrity of your chemicals.

1. Rinse a 250 mL bottle twice with distilled water. Measure 100 mL of distilled water with a graduated cylinder.
2. Pour this water into the 250 mL bottle. Put the lid on tightly and shake it vigorously for 5 minutes.
3. Uncap the bottle and take the temperature of the water. Be sure the tip of the thermometer does not touch the bottom or sides of the bottle. Wait 1 minute before reading the temperature.
4. Record the temperature on the Hydrology Investigation Data Work Sheet.
5. Follow directions to measure dissolved oxygen.

On the data sheet, record the value as mg/L DO for the distilled-water standard. The mg/L DO found using the shaken standard must be within 0.4 mg/L of the expected value for a shaken (thus saturated with oxygen) distilled water sample. To find the expected value for a saturated DO distilled water sample:

1. Look up the temperature of your standard in Table HYD-P-1.
2. Look at the corresponding solubility of oxygen (mg/L) and record it on the Calibration Data Work Sheet.

Table HYD-P-1: Solubility of Oxygen in Water Exposed to Air at 750 mm Hg Pressure

Temp °C	Solubility mg/L	Temp °C	Solubility mg/L	Temp °C	Solubility mg/L
0	14.6	16	9.9	32	7.3
1	14.2	17	9.7	33	7.2
2	13.8	18	9.5	34	7.1
3	13.5	19	9.3	35	7.0
4	13.1	20	9.1	36	6.8
5	12.8	21	8.9	37	6.7
6	12.5	22	8.7	38	6.6
7	12.1	23	8.6	39	6.5
8	11.9	24	8.4	40	6.4
9	11.6	25	8.3	41	6.3
10	11.3	26	8.1	42	6.2
11	11.0	27	8.0	43	6.1
12	10.8	28	7.8	44	6.0
13	10.5	29	7.7	45	5.9
14	10.3	30	7.6	46	5.8
15	10.1	31	7.4	47	5.7

Example: a standard temperature of 22° C has a corresponding DO solubility of 8.7 mg/L.

3. Look at the Calibration Value in Table HYD-P-2 corresponding to your elevation in meters and record it on the Calibration Data Work Sheet.

   Example: An elevation of 1,544 meters has a corresponding saturation calibration value of 0.83.
4. Multiply the solubility of oxygen found in Step 2 by the calibration found in Step 3.

   Example: At an altitude of 1,544 meters and a temperature of 22° C, you multiply (8.74 mg/L) x (0.83) = 7.25.
5. This value (7.25 in the example) is your expected value for a shaken distilled water standard.
6. Compare this value to the value for DO that you found when you tested your shaken, distilled water standard. If the value is not within 0.4 mg/L (LaMotte kit) or 1 mg/L (Hach kit), try the measurement again on the distilled water. If it is still off, but by less than 1 mg/L, record the DO value on the Calibration Investigation Data Work Sheet.
7. If you get a difference of more than 1 mg/L, report the value you get and replace the chemicals in your test kit before making more measurements. Recalibrate when you get fresh chemicals.

How to Measure Dissolved Oxygen

Sampling Procedure

1. Rinse the sampling bottle and hands with sample water three times. Rinse vial three times in distilled water.
2. Replace the cap on the bottle.
3. Submerge the bottle in sample water and remove the cap. Allow the container to fill.
4. Tap the bottle to release air bubbles.
5. While the bottle is submerged, replace the cap. Remove the capped bottle from the water.
6. Check to ensure that no bubbles are present in the bottle. If bubbles are found, repeat the sampling procedure.

Sample Preservation and Testing Procedure

1. Use a dissolved oxygen test kit that meets the specifications in the Toolkit of the GLOBE Program Teacher's Guide. Follow the instructions carefully. If a scoop is used to measure powdered chemicals, do not allow the scoop to come in contact with the liquid.
2. Record the values from the student groups on the Hydrology Investigation Data Work Sheet.
3. Take the average of the DO values measured by the student groups. If the values are all within 1 mg/L of the average, submit the average DO value to the GLOBE Student Data Server. Otherwise repeat the measurement.
4. Put all liquids in waste bottle.

DO test kits involve two overall parts - sample preservation (stabilization) and sample testing. The preservation part involves the addition to the sample of a chemical that precipitates in the presence of dissolved oxygen, followed by addition of a chemical that produces a colored solution. The testing part involves dropwise addition of a *titrant* solution until the color disappears. The DO value is calculated from the volume of titrant added.

Table HYD-P-2: Calibration Values For Various Atmospheric Pressures and Altitudes

Pressure mm Hg	Pressure kPa	elev m	Calibration value %
768	102.3	-84	1.01
760	101.3	0	1.00
752	100.3	85	0.99
745	99.3	170	0.98
787	98.8	256	0.97
730	97.3	343	0.96
722	96.3	431	0.95
714	95.2	519	0.94
707	94.2	608	0.93
699	93.2	698	0.92
692	92.2	789	0.91
684	91.2	880	0.90
676	90.2	972	0.89
669	89.2	1066	0.88
661	88.2	1160	0.87
654	87.1	1254	0.86
646	86.1	1350	0.85
638	85.1	1447	0.84
631	84.1	1544	0.83
623	83.1	1643	0.82
616	82.1	1743	0.81
608	81.1	1843	0.80
600	80.0	1945	0.79
593	79.0	2047	0.78
585	78.0	2151	0.77
578	77.0	2256	0.76
570	76.0	2362	0.75
562	75.0	2469	0.74
555	74.0	2577	0.73
547	73.0	2687	0.72
540	71.9	2797	0.71
532	70.9	2909	0.70
524	69.9	3203	0.69
517	68.9	3137	0.68
509	67.9	3253	0.67
502	66.9	3371	0.66

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pH Protocol

Purpose

To measure pH

Overview

The pH or acidity of the water sample is a key factor in determining what can live in the water.

Level

All

Time

5 minutes for the actual measurements

10 to 15 minutes in class and 5 minutes in the field for calibration in Method 2

Frequency

Weekly including calibration

Key Concepts

- pH and its measurement
- Temperature affects pH
- Calibration
- pH buffers and standards

Skills

- *Using* pH measuring equipment
- *Recording* data

Materials and Tools

For Method 1:

- pH indicator paper (Beginning)
- 50- or 100-mL beakers

For Method 2:

- pH pen (Intermediate/Advanced)
- One jewelry screwdriver (for calibration)
- Three 50- or 100-mL beakers
- 50 mL polyethylene bottle with top or clean baby food jar with lid
- pH buffer solution for pH 7

or:

- pH meter (Intermediate/Advanced)
- Five 50- or 100-mL beakers
- Three 50-mL polyethylene bottles with tops or clean baby food jars with lid
- Three pH buffer solutions for pH 4, 7, and 10

And for both pen and meter techniques:

- 100 mL graduated cylinder
- Paper towels
- Soft tissues
- Distilled water in a squeeze bottle
- Stirring rod or spoon
- Masking tape
- Permanent marker
- Latex gloves and safety goggles

Preparation

Condition the pH pen or pH meter probes according to manufacturer's instructions. Remember to allow enough time (> one hour). Often pH pens and probes last longer if they are kept wet. Set up calibration buffer solutions of known pH in class. Calibrate the pen and meter before going to the water site. Bring the tools and materials to the water site, including the buffer solutions.

Prerequisites

None

Background

This Protocol involves determining the pH of the water sample from your Hydrology Study Site. We suggest that beginning level students use pH indicator paper, intermediate level students use a pH pen, and advanced level students use a pH meter.

How To Measure pH

Method 1: pH indicator paper

Beginning Level

1. Rinse a 50 mL or 100 mL beaker at least twice with sample water.
2. Fill the beaker about halfway with water to be tested.
3. Dip one strip of indicator paper into the sample water for at least a minute. Make sure all four segments of the paper are immersed in sample water.
4. Remove the paper from the water and compare the resultant four color segments with the chart on the back of the pH indicator paper box. Try to find a sequence where all four segments on the sample paper match all four segments on the box.
5. If reading is unclear, it may be because the paper needs more time to fully react. The indicator paper takes longer to react in water with conductivities below 400 microSiemens/cm. See the Electrical Conductivity Protocol. If this is the case, place the paper back into the sample for an additional minute, and check again. Repeat until satisfied that the reading is accurate. If the reading is still unclear after 10 minutes, start over with a new strip of pH paper. If the test fails a second time, make this clear on your Hydrology Investigation Data Work Sheet.
6. Read the corresponding pH and record this value on your Hydrology Investigation Data Work Sheet. Report this value to the GLOBE Student Data Server.

Note: pH paper readings may not be accurate if your water sample has an electrical conductivity below 300 microSiemens/cm (pH paper does not function properly below this level). See the *Electrical Conductivity Protocol.*

Method 2: pH pen or pH meter

Intermediate and Advanced Levels

In order to measure the pH of your water sample using the pH meter you need to: (1) prepare buffer solutions, (2) calibrate the instruments, (3) recheck your instrument by measuring the buffers in the field, and (4) measure the pH of your sample in the field.

Calibration Procedure

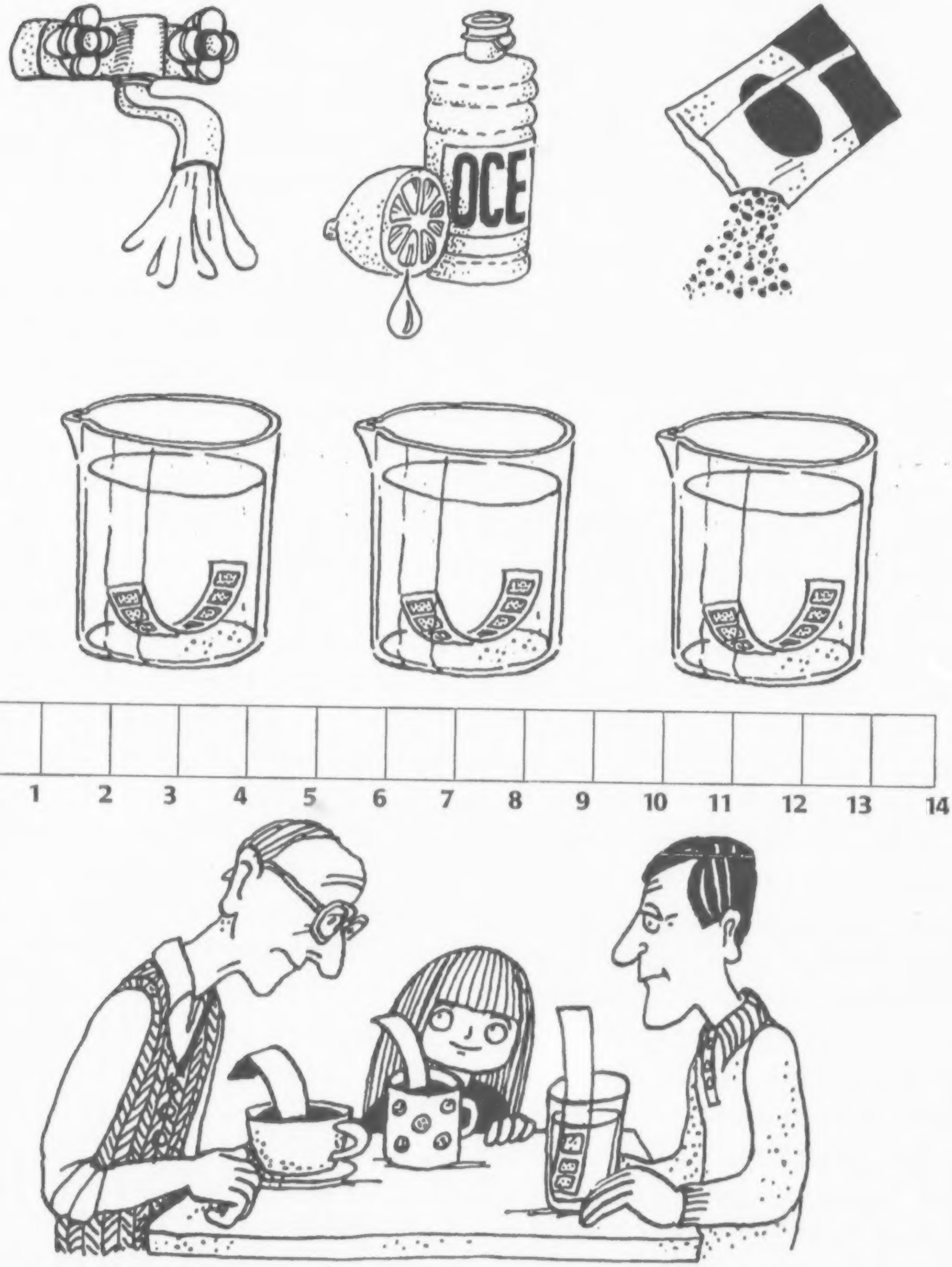
Calibration should be performed before each set of measurements. This procedure can be performed in the classroom before you go out in the field.

Step 1: Prepare the Buffer Solutions

Pre-mixed buffer solutions can be stored for 1 year, as long as they have not been contaminated. If you are using the powdered pillow buffer, then dissolve it in distilled water as described below. If you are using pre-mixed buffer solutions, measure 50 mL into a graduated cylinder and proceed to step 4.

For each pH buffer (4, 7, and 10):

1. Write the buffer pH and date on two pieces of masking tape. Place one on a clean, dry 100 mL beaker and the other on a 50 mL bottle or well cleaned baby food jar.
2. Using a graduated cylinder, measure 50 mL of distilled water and pour it into the beaker.
3. Over the beaker, completely cut open one end of a pillow of buffer powder, then squeeze and shake the pillow to release the powder into the water. Make sure all the powder is released into the water. Stir with stirring rod or spoon until all the powder dissolves.
4. Pour the buffer solution into the labeled bottle. Cap the bottle tightly. Discard after a month.
5. Continue preparing the other buffers, repeating steps 1-4 for each.


OCE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Source: Jan Smolík, 1996, TEREZA, Association for Environmental Education, Czech Republic

Step 2: Calibrate the pH pen or meter

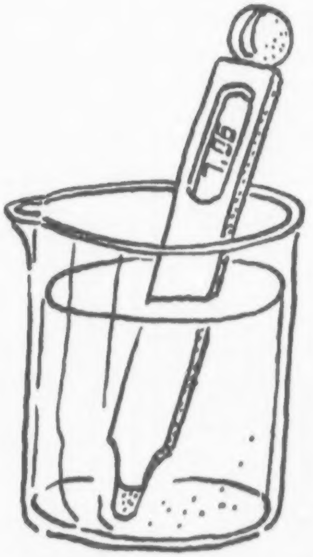
A. Calibration of the pH pen

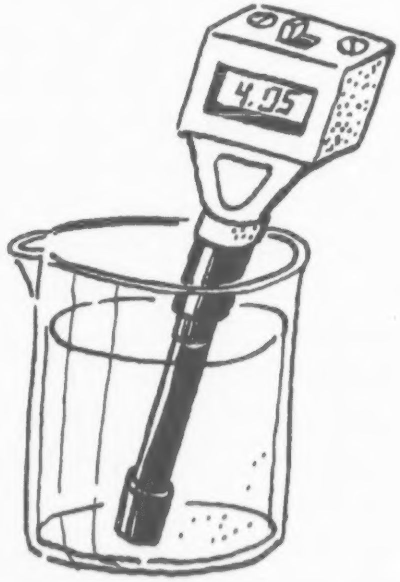
Note: If the pH pen does not have automatic temperature compensation, the buffer solution should be at 25° C.

1. Condition the electrode as described by the manufacturer.
2. Rinse the electrode (glass probe) and area around it twice with distilled water using a squeeze bottle and blot dry with a soft tissue after each rinse. Rinse into a discard beaker or sink, not into the pH buffer solution and do not touch the electrode (glass probe) with your fingers.
3. Turn the pen on with the switch on top, then immerse the electrode entirely in the pH 7.0 buffer solution. See Figure HYD-P-3.
4. Gently stir the buffer solution with the probe and wait for the reading to stabilize.
5. Use a jewelry screwdriver to turn the small screw in the hole in the back of the pen until the reading is exactly 7.0.
6. Remove the pH pen from the solution and rinse the electrode with distilled water; pour the buffer solution back into its labeled bottle and seal tightly.

B. Calibration of the pH meter

1. Condition the electrode (probe) as described in the manufacturer's instructions.
2. Rinse the electrode (glass probe) and area around it twice with distilled water using a squeeze bottle and blot dry with a soft tissue after each rinse. Rinse into a discard beaker or sink, not into the pH buffer solution and do not touch the electrode (glass probe) with your fingers.
3. Turn the meter on (by pressing the ON/OFF button). Push the CAL button to indicate that you will be calibrating the instrument.
4. Immerse the electrode in the pH 7.0 buffer solution, making sure that the electrode is entirely immersed. Do not immerse the instrument further than is necessary. See Figure HYD-P-3.
5. Gently stir the buffer solution with the electrode and wait for the display value to stabilize. Once the reading has stabilized, press the HOLD/CON button to accept the value and complete the calibration. If the electrode is still immersed in the buffer, the





Source: Jan Smolík, 1996, TEREZA, Association for Environmental Education, Czech Republic

display will read the same value as the pH of the buffer (i.e. 4, 7, or 10).

6. Remove the pH tester from the buffer solution, rinse the electrode with distilled water, and blot dry with soft tissue.
7. Repeat steps 3 through 6 using the pH 4 buffer and then using the pH 10 buffer.
8. Set the tester aside on a paper towel; turn the meter off by pushing the ON/OFF button.
9. Pour the buffer solution into their labeled bottles and cap them tightly.

Step 3: Recheck your pH pen or meter in the Field

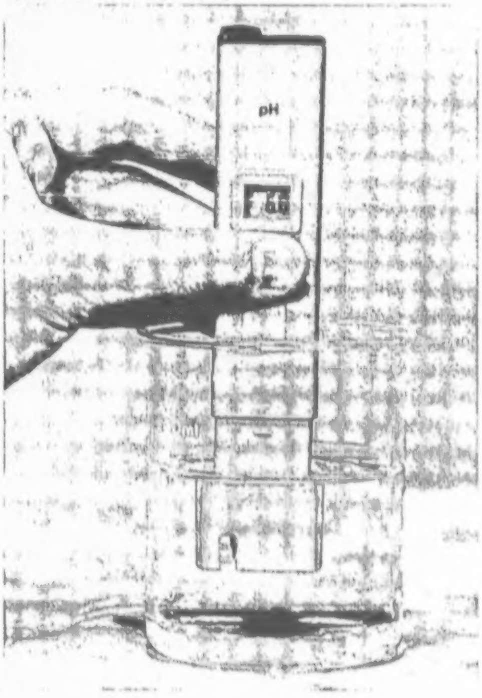
1. Take the pH buffer solutions into the field with you. Treat them as samples. Test the pH of the buffer solutions and record the field pH buffer values on the data sheets. If the values of the buffer solutions are more than + or - 0.2 pH units from the true value, go through the instrument calibration procedure again.
2. After you have tested the pen or meter with the buffer solutions, you are ready to measure the pH of the actual water sample.

pH Measurement Procedure

1. Rinse the electrode and the surrounding area with distilled water using the squeeze bottle. Blot the area dry with a soft tissue.
2. Fill a clean, dry 100 mL beaker to the 50 mL line with the water to be tested.
3. Immerse the electrode in the water. Be sure that the entire electrode is immersed, but avoid immersing it any further than necessary.
4. Stir once and then let the display value stabilize.
5. Once the display value is stable, read the pH value and record it in the Hydrology Investigation Data Work Sheet.
6. Repeat steps 1 through 5 for another sample as a quality control check. The two pH values should agree to within 0.2 which is the accuracy of this technique.
7. Rinse the probe with distilled water, blot it dry with soft tissue, replace the cap on the probe, and turn the instrument off.
8. Take the average of pH values measured by the student groups. If the recorded values are all within 0.2 of the average, report the average value to the GLOBE Student Data Server. If there is one outlier (a value far different from the rest) discard that value and calculate the average of the other values. If they are all now within 0.2 of this new average, report this new average to the GLOBE Student Data Server. If there is a wide scatter in results, discuss the procedure and the potential sources of error with the students, but do not report a value to the Data Server. Repeat the protocol if possible to produce a reportable measurement.

Note: pH pen or meter readings may not be accurate if your water sample has a conductivity below 100 microSiemens/cm (pH pens and meters do not function properly below this level). See the *Electrical Conductivity Protocol*.

Figure HYD-P-3: Using the pH pen



Electrical Conductivity Protocol

Purpose

To measure the conductivity of the water at the Hydrology Study Site

Overview

Conductivity is a measure of the amount of total dissolved solids in the water.

Time

5 minutes

Level

All

Frequency

Weekly including calibration

Key Concepts

Conductivity, factors affecting conductivity
Standardization, calibration
Accuracy, Precision

Skills

Using a conductivity meter
Recording data

Materials and Tools

Total dissolved solids tester (or conductivity tester)
Standard solution
Distilled water
Squeeze bottle
Soft tissue
Three 50 mL or 100 mL beakers
Jewelry screwdriver (for calibration)

Preparation

Perform the *Calibration* procedure below. Bring the tools and materials to the water site.

Prerequisites

None

Note: this measurement is for freshwater only. For salt and brackish waters measure salinity instead.

Background

Conductivity is measured in microSiemens/centimeter (µS/cm). A microSiemen is the same as a micromho.

Conductivity of a water sample is a measure of its ability to carry an electric current. The more impurities (total dissolved solids) in water, the greater its electrical conductivity. By measuring the conductivity of a water sample, the amount of total dissolved solids in the sample can be determined. To convert the electrical conductivity (microSiemens/cm) of a water sample to the concentration of total dissolved solids (ppm) in the sample, the conductivity must be multiplied by a factor of between 0.54 and 0.96 for natural waters. The value of this factor depends upon the type of dissolved solids. A widely accepted value to use when you are not determining the type of dissolved solids is 0.67.

TDS (ppm) = Conductivity (microSiemens/cm) x 0.67

Calibration

The conductivity meter should be calibrated before each set of measurements. Before use and every six months the temperature compensation should be checked. Calibration standards should be replaced annually.

Calibration

1. The standard solution should be tightly capped and kept refrigerated. The label on the bottle in which the solution is stored should include the date on which the solution was made or purchased.

2. Remove the cap from the meter.
3. Line up two clean and dry 100 mL beakers and fill each beaker with just enough standard solution to immerse the electrode. Note: Other standard solutions are available and acceptable. Please calibrate instrument accordingly.
4. Press the ON/OFF button to turn the tester ON.
5. Rinse the electrode (at the bottom tip of the pen) with distilled water from a squeeze bottle. Do not rinse above the brown line. Blot it dry with a soft tissue.
6. Immerse the electrode in the first beaker of standard solution for a second or two. Take the meter out of the first beaker and dip it into the second standard solution beaker, without rinsing the electrode. See Figure HYD-P-4.
7. Gently stir for a few seconds, then allow the display value to stabilize.
8. If the display does not read the standard value, you must adjust the instrument to read this number. Using a small screwdriver, adjust the calibration screw on the pen until the display reads the standard value. Note: Some conductivity meters may have different adjustments.
9. Discard the standard solution that was used in the two beakers. Do not return the standard solution used in this procedure to its original bottle!
10. Rinse the electrode with distilled water and blot it dry. Rinse the beakers thoroughly.
11. Press the ON/OFF button to turn the meter off. Cap the meter.

Temperature Compensation Check

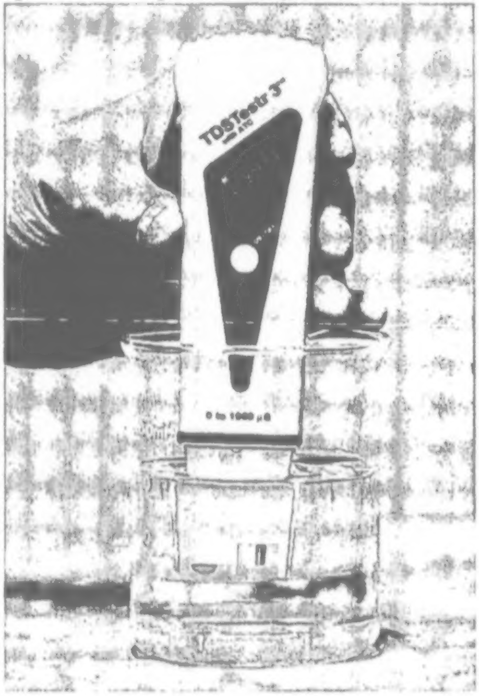
Conductivity measurements are affected by the water sample temperature. Your meter should be temperature compensated to give a conductivity reading equivalent to a temperature of 25° C.

Measure the conductivity of your standard at 5, 15, 25, and 35° C. If the conductivity reading is outside the specified range (+/– 40 µS/cm) for your standard at 25° C, then contact the manufacturer.

Quality Control in the Field

Whether the tester is calibrated in the classroom or in the field, the standard solution must be tested with the following protocol as if it were a water sample. When tested the standard should read its true value. If it does not, the instrument must be recalibrated, and the conductivity measurement made again.

Figure HYD-P-4: Using the Conductivity Meter



How to Measure Conductivity

1. Remove cap from the meter and press the ON/OFF button to turn the tester on.
2. Rinse the electrode with distilled water and blot it dry.
3. Fill a clean, dry, 100 mL beaker with water to be tested.
4. Immerse the electrode in the water sample. See Figure HYD-P-4.
5. Gently stir the sample for a few seconds, then allow the display value to stabilize.
6. Read the display value and record its value on the Hydrology Investigation Data Work Sheet.
7. Take the average of the electrical conductivity values measured by the student groups. If the recorded values are all within 40 microSiemens/cm of the average, report the average value to the GLOBE Student Data Server. If you have more than three groups and there is one outlier (a value far different from the rest), discard that value and calculate the average of the other values. If they are now all within 40 microSiemens/cm of this new average, report this new average to the GLOBE Student Data Server. If there is a wide scatter in results, discuss the procedure and the potential sources of error with the students, but do not report a value to the GLOBE Student Data Server. Repeat the protocol if possible to produce a reportable measurement.

Salinity Protocol

Purpose

To measure the salinity of the water sample using the hydrometer method

Overview

The salt content (salinity) of a water body is one of the main factors determining what organisms will be found there. The density of water is related to the amount of salt dissolved in it. A hydrometer is used to measure density. The salinity of the water is determined from the density and water temperature.

Level

All

Time

Actual measurement time is 10 minutes.

Frequency

Weekly

Key Concepts

- High and low tides
- Method of measuring salinity by density
- Specific gravity
- Salinity in water
- Standardization
- Accuracy
- Precision

Skills

- *Using* a hydrometer and thermometer
- *Reading* conversion tables
- *Designing* measurement strategies
- *Recording* data
- *Interpreting* results.

Materials and Tools

- Hydrometer
- Conversion table
- 500 mL clear plastic graduated cylinder
- Alcohol-filled thermometer
- Table salt (NaCl)
- Distilled water
- Balance
- 2 1-liter plastic bottles
- Masking tape

Preparation

Complete the *Calibration* activities below. Bring the tools and materials to the water site.

Prerequisites

A brief discussion of salinity and its relation to density

Practice by doing calibration

Note: This measurement is for salt and brackish waters only. For fresh waters measure conductivity instead.

Calibration and Quality Control

Standards should be run at least twice each year to verify your technique. Fresh standards should be prepared annually.

Salinity Standards

Salinity standards do not come with the Hydrometer, and need to be prepared as follows:

1. Add water to table salt to make a 35 ppt salinity standard. Use this salinity standard and a blank to test the accuracy of the hydrometer.

35 ppt standard:

1.1. Measure out 17.5 g NaCl (table salt) using an analytical balance. Pour this into a 500 mL graduated cylinder.

1.2. Fill the cylinder to the 500 mL line with distilled water.

1.3. Carefully swirl the solution until all the salt has dissolved.

1.4. Pour the solution into a 1-liter plastic bottle and label with masking tape (include the date).

Blank:

1.5 Measure out 500 mL of distilled water into a 1-liter plastic bottle and label with masking tape.

2. Perform the Protocol to measure the salinity of the standard and the blank. Where it says "sample water" use the standard or the blank.
3. Record the values measured for these standards on the Calibration Data Work Sheet.
4. If the blank gives a non-zero reading, rinse your glassware and graduated cylinder at least 3 times, and repeat the measurement. If still not zero, get a new source of distilled water.
5. If salinity standard is off by more than 2 ppt, prepare a new standard and repeat the measurement.

Times of High and Low Tide

Obtain the times of high and low tide for the location nearest your site for which these are available. The times reported should be for the high or low tide immediately preceding and following the time you take your measurements. Record these times and the place where they occur on your Hydrology Investigation Data Work Sheet and report them with your other data to the GLOBE Student Data Server.

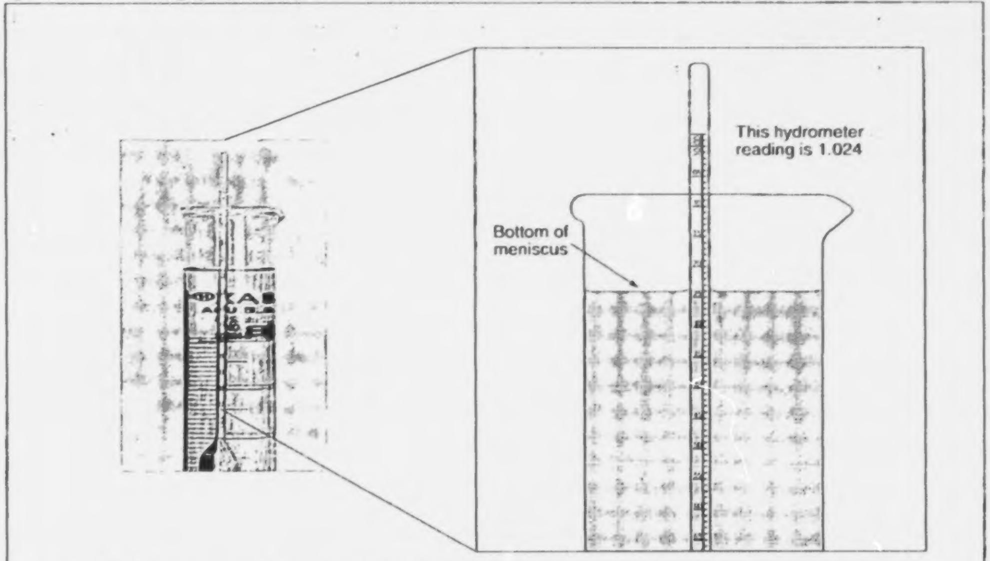
How to Measure Salinity

Note: Before using the thermometer in this protocol, test it for accuracy following the instructions in *Maximum, Minimum, and Current Temperature Protocol* of the *Atmosphere Investigation*.

1. Rinse the 500 mL clear plastic graduated cylinder at least twice with sample water.
2. Fill the cylinder with sample water until the water level is 2 to 3 cm from the top of the cylinder.
3. Determine the temperature of your sample following the Water Temperature Protocol and record this value on the Hydrology Investigation Data Work Sheet.
4. Place the hydrometer in the cylinder and allow it to settle. Follow the manufacturer's instructions that came with the hydrometer. The hydrometer should not touch the cylinder walls, and be sure to take the reading from the *bottom* of the meniscus. Read the specific gravity from the hydrometer scale. Reading to three decimal places is acceptable. Older students can practice reading to four decimal places and interpolating between the values given in Table HYD-P-3. Record this value on the Hydrology Investigation Data Work Sheet. See Figure HYD-P-5.
5. Using the temperature and specific gravity values, read the salinity of the sample from Table HYD-P-3. To find the salinity value for your water sample:
   5.1. Look up the temperature and specific gravity of the sample in Table HYD-P-3.
   5.2. Look at the corresponding salinity (ppt) and record it on the Hydrology Investigation Data Work Sheet. For example, a water sample temperature of 22° C and specific gravity of 1.0070 has a salinity of 10.6 ppt.

6. Repeat steps 2 - 5 for at least two additional samples. Different student groups can make these additional measurements.
7. Take the average of the salinity values measured for the different samples. If the recorded values are all within 2 ppt of the average, proceed to step 8. If they are not within 2 ppt of the average, students should repeat the measurement using new samples, then record and average the new values. If there is still one outlier (a value far different from the rest) discard that value, average the remaining values, and if they are now within 2 ppt of this new average, proceed to step 8. If there is still a wide spread in values, discuss the procedures with the students and repeat the measurement if possible.
8. Submit to the GLOBE Student Data Server the temperature, specific gravity, and salinity from the student(s) whose salinity is closest to the average. If only two measurements were used to calculate the average, report the temperature, specific gravity, and salinity from either group.

Figure HYD-P-5: Reading Specific Gravity



Note: Hydrology measurements are read from the bottom of the meniscus.

*Table HYD-P-3: Salinity (parts per thousand) as a function of density and temperature**

	Temperature of Water in Graduated Cylinder (° C)																
Observed Reading	**-2.0**	**-1.0**	**0.0**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**	**9.0**	**10.0**	**11.0**	**12.0**	**13.0**	**14.0**
0.9980																	
0.9990																	
1.0000																	
1.0010	0.7	0.6	0.6	0.5	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.5	0.6	0.6	0.7	0.8
1.0020	2.0	1.9	1.9	1.8	1.6	1.6	1.6	1.5	1.5	1.6	1.6	1.6	1.8	1.9	2.0	2.1	2.3
1.0030	3.3	3.2	3.1	2.9	2.9	2.8	2.8	2.8	2.8	2.8	2.9	2.9	3.1	3.2	3.3	3.4	3.6
1.0040	4.5	4.4	4.2	4.2	4.1	4.1	4.1	4.1	4.1	4.1	4.2	4.2	4.4	4.5	4.6	4.8	4.9
1.0050	5.8	5.7	5.5	5.4	5.4	5.4	5.3	5.3	5.4	5.4	5.4	5.5	5.5	5.7	5.8	5.9	6.2
1.0060	7.0	6.8	6.8	6.7	6.6	6.6	6.6	6.6	6.6	6.7	6.7	6.8	6.8	7.0	7.1	7.2	7.5
1.0070	8.1	8.1	8.0	7.9	7.9	7.9	7.9	7.9	7.9	7.9	8.0	8.1	8.1	8.3	8.4	8.5	8.8
1.0080	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.3	9.3	9.4	9.6	9.7	9.8	10.0
1.0090	10.6	10.5	10.5	10.4	10.4	10.4	10.4	10.4	10.5	10.5	10.6	10.6	10.7	10.9	11.0	11.1	11.3
1.0100	11.9	11.8	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.8	11.8	11.9	12.0	12.2	12.3	12.4	12.6
1.0110	13.1	13.0	13.0	12.8	12.8	12.8	12.8	13.0	13.0	13.1	13.1	13.2	13.4	13.5	13.6	13.7	13.9
1.0120	14.3	14.3	14.1	14.1	14.1	14.1	14.1	14.1	14.3	14.3	14.4	14.5	14.7	14.8	14.9	15.0	15.2
1.0130	15.6	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.6	15.7	15.8	15.8	16.0	16.2	16.3	16.5
1.0140	16.7	16.7	16.6	16.6	16.6	16.6	16.6	16.7	16.7	16.9	17.0	17.0	17.1	17.3	17.5	17.7	17.8
1.0150	18.0	17.9	17.9	17.9	17.9	17.9	17.9	17.9	18.0	18.0	18.2	18.3	18.4	18.6	18.8	19.0	19.1
1.0160	19.2	19.2	19.1	19.1	19.1	19.1	19.2	19.2	19.3	19.3	19.5	19.6	19.7	19.9	20.1	20.3	20.4
1.0170	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.5	20.5	20.6	20.8	20.9	21.0	21.2	21.3	21.6	21.7
1.0180	21.7	21.7	21.7	21.6	21.6	21.7	21.7	21.7	21.8	22.0	22.1	22.2	22.3	22.5	22.6	22.9	23.0
1.0190	22.9	22.9	22.9	22.9	22.9	22.9	23.0	23.0	23.1	23.3	23.4	23.5	23.6	23.8	23.9	24.2	24.3
1.0200	24.2	24.2	24.2	24.0	24.2	24.2	24.2	24.3	24.3	24.4	24.6	24.7	24.8	25.1	25.2	25.5	25.6
1.0210	25.3	25.3	25.3	25.3	25.3	25.5	25.5	25.6	25.6	25.7	25.9	26.0	26.1	26.4	26.5	26.8	26.9
1.0220	26.6	26.6	26.6	26.6	26.6	26.6	26.8	26.8	26.9	27.0	27.2	27.3	27.4	27.7	27.8	28.1	28.2
1.0230	27.8	27.8	27.8	27.8	27.8	27.9	27.9	28.1	28.2	28.3	28.5	28.6	28.7	28.9	29.1	29.4	29.5
1.0240	29.1	29.1	29.1	29.1	29.1	29.1	29.2	29.4	29.5	29.5	29.8	29.9	30.0	30.2	30.4	30.6	30.8
1.0250	30.3	30.3	30.3	30.3	30.4	30.4	30.6	30.6	30.7	30.8	30.9	31.1	31.3	31.5	31.7	31.9	32.1
1.0260	31.6	31.6	31.6	31.6	31.6	31.7	31.7	31.9	32.0	32.1	32.2	32.4	32.6	32.8	33.0	33.2	33.4
1.0270	32.8	32.8	32.8	32.9	32.9	32.9	33.0	33.2	33.3	33.4	33.5	33.7	33.9	34.1	34.3	34.5	34.7
1.0280	33.9	34.1	34.1	34.1	34.1	34.2	34.3	34.5	34.5	34.7	34.8	35.0	35.1	35.4	35.6	35.8	36.0
1.0290	35.2	35.2	35.2	35.4	35.4	35.5	35.5	35.6	35.8	35.9	36.2	36.3	36.4	36.7	36.8	37.1	37.3
1.0300	36.4	36.5	36.5	36.5	36.7	36.7	36.8	36.9	37.1	37.2	37.3	37.6	37.7	38.0	38.1	38.4	38.6
1.0310	37.7	37.7	37.7	37.8	37.8	38.0	38.1	38.2	38.4	38.5	38.6	38.9	39.0	39.3	39.4	39.7	39.9

* Adapted from LaMotte hydrometer instructions.

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Table HYD-P-3: Salinity (parts per thousand) as a function of density and temperature - continued

	Temperature of Water in Graduated Cylinder (° C)																
Observed Reading	**15.0**	**16.0**	**17.0**	**18.0**	**18.5**	**19.0**	**19.5**	**20.0**	**20.5**	**21.0**	**21.5**	**22.0**	**22.5**	**23.0**	**23.5**	**24.0**	**24.5**
0.9980																	
0.9990										0.0	0.1	0.2	0.3	0.5	0.6	0.7	
1.0000		0.0	0.2	0.3	0.5	0.6	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.6	1.8	1.9	2.0
1.0010	1.0	1.2	1.5	1.6	1.8	1.9	2.0	2.1	2.3	2.4	2.5	2.5	2.7	2.8	2.9	3.1	3.2
1.0020	2.4	2.5	2.8	2.9	3.1	3.2	3.3	3.4	3.6	3.7	3.8	4.0	4.1	4.2	4.4	4.6	4.8
1.0030	3.7	3.8	4.1	4.2	4.4	4.5	4.6	4.8	4.9	5.0	5.1	5.3	5.4	5.5	5.8	5.9	6.1
1.0040	5.0	5.1	5.4	5.5	5.7	5.8	5.9	6.1	6.2	6.3	6.4	6.6	6.7	7.0	7.1	7.2	7.4
1.0050	6.3	6.6	6.7	7.0	7.1	7.1	7.2	7.4	7.5	7.6	7.7	7.9	8.1	8.3	8.4	8.5	8.7
1.0060	7.6	7.9	8.0	8.3	8.4	8.5	8.7	8.8	8.9	9.1	9.2	9.3	9.4	9.6	9.7	9.8	10.1
1.0070	8.9	9.2	9.3	9.6	9.7	9.8	10.0	10.1	10.2	10.4	10.5	10.6	10.7	10.9	11.0	11.3	11.4
1.0080	10.2	10.5	10.6	10.9	11.0	11.1	11.3	11.4	11.5	11.7	11.8	11.9	12.0	12.2	12.4	12.6	12.7
1.0090	11.5	11.8	11.9	12.2	12.3	12.4	12.6	12.7	12.8	13.0	13.1	13.2	13.4	13.6	13.7	13.9	14.0
1.0100	12.8	13.1	13.2	13.5	13.6	13.7	13.9	14.0	14.1	14.3	14.4	14.5	14.8	14.9	15.0	15.2	15.3
1.0110	14.1	14.4	14.5	14.8	14.9	15.0	15.2	15.3	15.4	15.6	15.7	16.0	16.1	16.2	16.3	16.5	16.7
1.0120	15.4	15.7	15.8	16.1	16.2	16.3	16.5	16.6	16.7	17.0	17.1	17.3	17.4	17.5	17.7	17.9	18.0
1.0130	16.7	17.0	17.1	17.4	17.5	17.7	17.8	17.9	18.0	18.3	18.4	18.6	18.7	18.8	19.1	19.2	19.3
1.0140	18.0	18.3	18.6	18.7	18.8	19.0	19.1	19.3	19.5	19.6	19.7	19.9	20.0	20.1	20.4	20.5	20.6
1.0150	19.3	19.6	19.9	20.0	20.1	20.4	20.5	20.6	20.8	20.9	21.0	21.2	21.3	21.6	21.7	21.8	22.0
1.0160	20.6	20.9	21.2	21.3	21.4	21.7	21.8	22.0	22.1	22.2	22.3	22.5	22.7	22.9	23.0	23.3	23.4
1.0170	22.0	22.2	22.5	22.7	22.9	23.0	23.1	23.3	23.4	23.5	23.6	23.8	24.0	24.2	24.3	24.6	24.7
1.0180	23.3	23.5	23.8	24.0	24.2	24.3	24.4	24.6	24.7	24.8	24.9	25.2	25.3	25.5	25.6	25.9	26.0
1.0190	24.6	24.8	25.1	25.3	25.5	25.6	25.7	25.9	26.0	26.1	26.4	26.5	26.6	26.8	27.0	27.2	27.3
1.0200	25.9	26.1	26.4	26.6	26.8	26.9	27.0	27.2	27.3	27.4	27.7	27.8	27.9	28.2	28.3	28.5	28.6
1.0210	27.2	27.4	27.7	27.9	28.1	28.2	28.3	28.5	28.6	28.9	29.0	29.1	29.2	29.5	29.6	29.8	30.0
1.0220	28.5	28.7	29.0	29.2	29.4	29.5	29.6	29.8	30.0	30.2	30.3	30.4	30.7	30.8	30.9	31.2	31.3
1.0230	29.8	30.0	30.3	30.6	30.7	30.8	30.9	31.2	31.3	31.5	31.6	31.7	32.0	32.1	32.2	32.5	32.6
1.0240	31.1	31.3	31.6	31.9	32.0	32.1	32.2	32.5	32.6	32.8	32.9	33.2	33.3	33.4	33.7	33.8	33.9
1.0250	32.4	32.6	32.9	33.2	33.3	33.4	33.7	33.8	33.9	34.1	34.2	34.5	34.6	34.7	35.0	35.1	35.2
1.0260	33.7	33.9	34.2	34.5	34.6	34.7	35.0	35.1	35.2	35.4	35.6	35.8	35.9	36.0	36.3	36.4	36.7
1.0270	35.0	35.2	35.5	35.8	35.9	36.2	36.3	36.4	36.5	36.7	36.9	37.1	37.2	37.5	37.6	37.8	38.0
1.0280	36.3	36.5	36.8	37.1	37.2	37.5	37.6	37.7	37.8	38.1	38.2	38.4	38.5	38.8	38.9	39.1	39.3
1.0290	37.6	37.8	38.1	38.4	38.6	38.8	38.9	39.0	39.1	39.4	39.5	39.7	39.9	40.1	40.2	40.5	40.6
1.0300	38.9	39.1	39.4	39.7	39.9	40.1	40.2	40.3	40.6	40.7	40.8	41.0	41.2	41.4	41.6	41.8	41.9
1.0310	40.2	40.5	40.7	41.0	41.2	41.4	41.5	41.8	41.9	42.0	42.1	42.3	42.5				

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Table HYD-P-3: Salinity (parts per thousand) as a function of density and temperature - continued

	Temperature of Water in Graduated Cylinder (° C)																
Observed Reading	**25.0**	**25.5**	**26.0**	**26.5**	**27.0**	**27.5**	**28.0**	**28.5**	**29.0**	**29.5**	**30.0**	**30.5**	**31.0**	**31.5**	**32.0**	**32.5**	**33.0**
0.9980			0.1	0.2	0.3	0.6	0.7	0.8	1.1	1.2	1.5	1.6	1.9	2.0	2.3	2.4	
0.9990	0.8	1.0	1.2	1.4	1.5	1.8	1.9	2.0	2.3	2.4	2.5	2.8	2.9	3.2	3.4	3.6	3.8
1.0000	2.1	2.4	2.5	2.7	2.9	3.1	3.2	3.4	3.6	3.7	4.0	4.1	4.4	4.5	4.8	4.9	5.1
1.0010	3.4	3.6	3.8	4.0	4.2	4.4	4.5	4.8	4.9	5.1	5.1	5.4	5.5	5.8	5.9	6.2	6.4
1.0020	4.9	5.0	5.1	5.4	5.5	5.7	5.9	6.1	6.3	6.4	6.6	6.8	7.0	7.2	7.5	7.6	7.9
1.0030	6.2	6.3	6.6	6.7	6.8	7.1	7.2	7.4	7.6	7.7	8.0	8.1	8.4	8.5	8.8	9.1	9.2
1.0040	7.5	7.7	7.9	8.0	8.3	8.4	8.5	8.8	8.9	9.2	9.3	9.6	9.7	10.0	10.1	10.4	10.5
1.0050	8.9	9.1	9.2	9.3	9.6	9.7	10.0	10.1	10.2	10.5	10.6	10.9	11.0	11.3	11.5	11.7	11.9
1.0060	10.2	10.4	10.5	10.7	10.9	11.0	11.3	11.4	11.7	11.8	12.0	12.2	12.4	12.6	12.8	13.1	13.2
1.0070	11.5	11.7	11.9	12.0	12.2	12.4	12.6	12.8	13.0	13.1	13.4	13.6	13.7	14.0	14.1	14.4	14.7
1.0080	12.8	13.0	13.2	13.4	13.6	13.7	13.9	14.1	14.3	14.5	14.7	14.9	15.2	15.3	15.6	15.7	16.0
1.0090	14.1	14.4	14.5	14.7	14.9	15.0	15.3	15.4	15.7	15.8	16.1	16.2	16.5	16.6	16.9	17.1	17.3
1.0100	15.6	15.7	15.8	16.1	16.2	16.5	16.6	16.7	17.0	17.1	17.4	17.5	17.8	18.0	18.2	18.4	18.7
1.0110	16.9	17.0	17.3	17.4	17.5	17.8	17.9	18.2	18.3	18.6	18.7	19.0	19.1	19.3	19.6	19.7	20.0
1.0120	18.2	18.3	18.6	18.7	19.0	19.1	19.3	19.5	19.6	19.9	20.1	20.3	20.5	20.6	20.9	21.2	21.3
1.0130	19.5	19.7	19.9	20.0	20.3	20.4	20.6	20.8	21.0	21.2	21.4	21.6	21.8	22.1	22.2	22.5	22.7
1.0140	20.9	21.0	21.2	21.4	21.6	21.8	22.0	22.2	22.3	22.6	22.7	23.0	23.1	23.4	23.6	23.8	24.0
1.0150	22.2	22.3	22.5	22.7	22.9	23.1	23.3	23.5	23.6	23.9	24.0	24.3	24.6	24.7	24.9	25.2	25.3
1.0160	23.5	23.6	23.9	24.0	24.3	24.4	24.7	24.8	25.1	25.2	25.5	25.6	25.9	26.1	26.3	26.5	26.8
1.0170	24.8	25.1	25.2	25.3	25.6	25.7	26.0	26.1	26.4	26.5	26.8	27.0	27.2	27.4	27.7	27.8	28.1
1.0180	26.1	26.4	26.5	26.8	26.9	27.2	27.3	27.6	27.7	27.9	28.1	28.3	28.5	28.7	29.0	29.2	29.4
1.0190	27.6	27.7	27.8	28.1	28.2	28.5	28.6	28.9	29.0	29.2	29.5	29.6	29.9	30.0	30.3	30.6	30.8
1.0200	28.9	29.0	29.2	29.4	29.6	29.8	30.0	30.2	30.4	30.6	30.8	30.9	31.2	31.5	31.6	31.9	32.1
1.0210	30.2	30.3	30.6	30.7	30.9	31.1	31.3	31.5	31.7	32.0	32.1	32.4	32.5	32.8	33.0	33.3	33.4
1.0220	31.5	31.7	31.9	32.0	32.2	32.5	32.6	32.9	33.0	33.3	33.4	33.7	33.9	34.1	34.3	34.6	34.8
1.0230	32.8	33.0	33.2	33.4	33.5	33.8	33.9	34.2	34.5	34.6	34.8	35.0	35.2	35.5	35.6	35.9	36.2
1.0240	34.2	34.3	34.5	34.7	35.0	35.1	35.4	35.5	35.8	35.9	36.2	36.4	36.5	36.8	37.1	37.2	37.5
1.0250	35.5	35.6	35.9	36.0	36.3	36.4	36.7	36.8	37.1	37.2	37.5	37.7	37.8	38.1	38.4	38.6	38.8
1.0260	36.8	36.9	37.2	37.3	37.6	37.7	38.0	38.2	38.4	38.6	38.8	39.0	39.3	39.4	39.7	39.9	40.2
1.0270	38.1	38.4	38.5	38.8	38.9	39.1	39.3	39.5	39.8	39.9	40.2	40.3	40.6	40.8	41.0	41.2	41.5
1.0280	39.4	39.7	39.8	40.1	40.2	40.5	40.7	40.8	41.1	41.2	41.5						
1.0290	40.8	41.0	41.2	41.4	41.6	41.8											

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Optional Salinity Titration Protocol

Purpose

To measure the salinity of the water sample using the more accurate salinity titration method

Overview

The major dissolved constituents (salts) in sea water are found in relatively constant proportions. By measuring the concentration of any one of them in sea water samples, in this case chloride (chlorinity), the water sample's salinity can then be inferred.

Level

Intermediate, Advanced

Time

10-15 minutes

Frequency

Weekly

Calibration every six months

Key Concepts

- Method of measuring salinity using the concentration of one chemical constituent of sea water
- Constancy of sea water composition
- Standardization
- Accuracy
- Salinity in water
- High and low tides
- Precision

Skills

- *Using* the salinity titration test procedure
- *Designing* measurements strategies
- *Recording* data
- *Interpreting* results

Materials and Tools

- Salinity Titration Test Kit (See Toolkit)
- Data Work Sheets
- Latex gloves
- 1-liter plastic bottle
- Table salt
- Distilled water
- Masking tape
- 500 mL clear plastic graduated cylinder
- Balance

Preparation

Complete the *Calibration* activities below.

Prerequisites

A brief discussion of the relation of salinity to chlorinity and how titration is used to measure them

Practice by doing calibration.

Note: This measurement is for salt and brackish waters only. For fresh waters measure conductivity instead.

Note: For background information and special considerations for brackish and salty water Hydrology Study Sites, please refer to those sections of the *Salinity Protocol*.

Calibration and Quality Control

Calibration should be performed at least every six months to verify your technique and the integrity of your chemicals. Fresh standards should be prepared annually.

Salinity Standards

Salinity standards do not come with the Salinity Titration Kit, and one needs to be prepared as follows:

1. Add water to table salt to make a sea water titration standard of 38.6 ppt salinity. Use this standard to test the accuracy of the Salinity Titration Test Kit.
   1.1. Measure out 17.5 g NaCl (table salt) using an analytical balance. Pour this into a 500 mL graduated cylinder.
   1.2. Fill the cylinder to the line with distilled water.
   1.3. Carefully swirl the solution to mix the standard.
   1.4. Pour the solution into a 1-liter plastic bottle and label with masking tape (include the date).
2. Follow directions in the Protocol section to measure the standards. Where it says "sample water" use the standard that you made.
3. Record the value of the standards after testing on the Hydrology Investigation Data Work Sheet.
4. If salinity standards are off by more than 0.4 ppt, prepare new standards and repeat the measurement.

Note: The sea water titration standard concentration is corrected for sea water composition. For example, to calculate the sea water salinity from 17.5 g NaCl in 500 mL (35 ppt NaCl), take into account the molecular composition of NaCl (the ratio of the molecular weight of Cl to NaCl is 0.61): 35 ppt x 0.61 = 21.35 ppt chlorinity. The salinity of the standard is 21.35 x 1.80655 = 38.6 ppt because in sea water chloride ions comprise 55.354% of the total dissolved salts by weight.

Times of High and Low Tide

Obtain the times of high and low tide for the location nearest your site for which these are available. The times reported should be for the high or low tide immediately preceding and following the time you make your measurements. Record these times and place they occur on your Hydrology Investigation Data Work Sheet and report them with your other data to the GLOBE Student Data Server.

How to Measure Salinity

1. Use a salinity titration test kit which meets the *Globe Instruments Specifications* in the *Toolkit*. The kits are based on the technique of adding a color indicator to the sample and then adding an acid titrant dropwise until a color change is observed.
2. Follow the manufacturer's instructions on the kit. To titrate more saline water than 20 parts per thousand (ppt), refill the titrator with acid, keeping a record of the total amount of acid used.
3. Record the salinity in ppt on the Hydrology Investigation Data Work Sheet.
4. Take the average of the salinity values measured by the student groups. If the recorded values are all within 0.4 ppt of the average, submit the average to the GLOBE Student Data Server. If they are not within 0.4 ppt of the average have the students retitrate the sample, then record and average the new values. If there is still one outlier (a value far different from the rest) discard that value and average the rest of the values. If they are now all within 0.4 ppt of the new average, report this new average to the GLOBE Student Data Server. If there is a wide scatter (more than 0.4 ppt) in results, discuss the procedure and the potential sources of error with the students, but do not report a value to the Data Server. Repeat the protocol to produce a reportable measurement.
5. Put all liquids in waste bottles.

Alkalinity Protocol

Purpose

To measure the alkalinity of the water sample

Overview

Alkalinity is closely related to the kinds of aquatic life that will survive in water.

Time

15 minutes

Level

Intermediate, Advanced

Frequency

Weekly

Calibration every six months

Key Concepts

Alkalinity, natural factors affecting alkalinity
Method of measurement of alkalinity
Standardization
Accuracy, Precision

Skills

Using the alkalinity test procedure properly
Recording data

Materials and Tools

Alkalinity Test Kit (See *Toolkit*)
Baking soda (sodium bicarbonate)
Distilled water bottle
Distilled water
500 mL beaker
100 mL graduated cylinder
500 mL graduated cylinder
Stirring rod
Data sheets
Sample bottle
Latex gloves/safety goggles
Balance

Preparation

Complete the Calibration/Quality Control activities below. Bring the tools and materials to the water site.

Prerequisites

None

Calibration and Quality Control

Preparing the Baking Soda Standard

1. Using your balance, weigh out 1.9 g baking soda and add it to your 500 mL graduated cylinder. Make sure to transfer all of the baking soda to the cylinder.
2. Fill the 500 mL graduated cylinder to the 500 mL mark with distilled water.
3. Pour this solution into the 500 mL beaker, and stir it with a stirring rod to make sure all of the baking soda has dissolved.
4. Pour 15 mL from the beaker into the 100 mL graduated cylinder.
5. Rinse the 500 mL graduated cylinder with distilled water first. Pour the 15 mL of your baking soda solution into the 500 mL graduated cylinder.
6. Fill the 500 mL graduated cylinder to the 500 mL mark with distilled water.
7. The solution in your 500 mL graduated cylinder is your standard.

The true alkalinity of this baking soda standard is 68 mg/L as $CaCO_3$. The true value for distilled water is usually below 14 mg/L.

Quality Control Procedure

1. Do the alkalinity protocol below using the baking soda standard instead of your water sample.
2. Record the alkalinity value in mg/L as $CaCO_3$ on the Calibration Data Work Sheet.

If the baking soda standard is off by more than the mg/L equivalent of one drop or one gradation of the titrator for your alkalinity kit, prepare a new baking soda standard making sure your weights and dilutions are accurate. If you are still off by more than the mg/L equivalent of one drop or one gradation of the titrator for your alkalinity kit, you may need to get new reagents for your kit.

How to Measure Alkalinity

If your alkalinity kit has both a low range protocol and a high range protocol, use the low range protocol unless your water sample has an alkalinity greater than about 125 mg/L as $CaCO_3$. This will enable you to make more precise measurements.

1. Use an alkalinity test kit which meets the *GLOBE Instruments Specifications* in the *Toolkit*. Follow the manufacturer's instructions. The kits are based on the technique of adding a color indicator to the sample and then adding an acid titrant dropwise until a color change is observed.
2. Record the total alkalinity in mg/L as $CaCO_3$ on the Hydrology Investigation Data Work Sheet.
3. Take the average of the alkalinity values measured by the student groups. If the recorded values are all within the equivalent in mg/L of one drop or one gradation of the titrator for your test kit of the average, report the average value to the GLOBE Student Data Server. If you have more than three groups and there is one outlier (a value far different from the rest) discard that value and calculate the average of the other values. If they are now all within the equivalent in mg/L of one drop or one gradation of the titrator for your test kit of this new average, report this new average to the GLOBE Student Data Server. If there is a wide scatter (more than the equivalent of one drop or one gradation of the titrator) in results, discuss the procedure and the potential sources of error with the students, but do not report a value to the Data Server. Repeat the protocol to produce a reportable measurement.

Nitrate Protocol

Purpose

To obtain nitrate nitrogen measurements of the water at the Hydrology Study Site

Overview

Measuring nitrate levels in water is an important step in the determination of water quality. Nitrogen exists in water in numerous forms, two of which are nitrate (NO_3^-) and nitrite (NO_2^-). Of these forms, nitrate is usually the most important. Nitrite can be found in suboxic waters. Nitrate is an essential nutrient for growth of algae and other aquatic plants, and can be present at high levels due to inputs from a variety of sources. Nitrate is very difficult to measure directly, so it is reduced to nitrite and the resulting nitrite concentration is measured. The measurement gives the combined concentration of nitrite (if present) and nitrate concentrations. Because we are interested in the nitrate measurement, background levels of nitrite also have to be measured. Nitrate measurements are reported as nitrate nitrogen (mg/L). Nitrite measurements are reported as nitrite nitrogen (mg/L).

Level

Intermediate and Advanced

Time

About 15 minutes

Frequency

Weekly

Calibration every six months

Key Concepts

Colorimetric methods for water analysis
Nitrate in water

Skills

Doing a colorimetric analysis
Designing measurement strategies
Recording data

Materials and Tools

50 mL beaker or flask
Nitrate Test Kit (if you have salt or brackish water, be sure to use an appropriate test kit)
100 mL graduated cylinder
500 mL graduated cylinder
3 500-mL bottles or jars
Distilled water

Preparation

Read all instructions carefully in the test kit before beginning. Make sure kit includes all the materials listed. Review proper levels of nitrate that are acceptable in water (10 mg/L nitrate-nitrogen for drinking water).

Prerequisites

A brief discussion of why nitrate is important in water

A discussion of the difference between nitrate nitrogen and nitrate

A discussion of the difference between nitrate and nitrite

Practice by doing calibration.

Calibration and Quality Control

Standards should be run at least every six months to verify your technique and the integrity of your chemicals. Fresh standard should be prepared each time unless the standard has been stabilized. Measuring the standards will help to clarify the instructions in test kits where wording may be unclear.

Nitrate Standards

Nitrate standards do not come with test kits and need to be either ordered separately or prepared as follows:

- **Stock Nitrate Solution:** Dry KNO_3 (potassium nitrate) in an oven for 24 hours at 105° C. Then dissolve 3.6 g of KNO_3 in distilled water. Dilute to 500 mL in your 500 mL graduated cylinder using distilled water. Carefully swirl the solution to mix (do not shake). Store in a 500 ml bottle or jar. Label with masking tape (include date). This makes a 7200 mg/L KNO_3 (or a 1000 mg/L nitrate nitrogen) solution.

  Note: To calculate nitrate nitrogen ($N0_3$-N), take into account the molecular composition of KNO_3 (the ratio of the molecular weight of N to KNO_3 is 0.138): 7200 mg/L KNO_3 x $0.138 \cong 1000$ mg/L nitrate nitrogen ($N0_3$-N).
- **Standard Nitrate Solution:** Measure 50 mL of the stock nitrate solution using the 100 mL graduated cylinder. Pour into the 500 mL graduated cylinder and dilute to 500 mL with distilled water. Carefully swirl the solution to mix. The result is a 100 mg/L nitrate nitrogen standard. Store in a 500 ml bottle or jar. Label with masking tape (include date).
- Make a new stock nitrate solution each time a calibration is conducted if the stock solution has not been preserved. Standard nitrate solutions should be made fresh each time regardless of whether the stock solution has been preserved or not. The stock nitrate solution can be preserved and stabilized for up to six months using chloroform ($CHCl_3$) if you have safe access to this chemical. To preserve a stock nitrate standard add 1 mL of $CHCl_3$ to 500 mL of stock solution.

Quality Control Procedure

1. Dilute the 100 mg/L standard to make a 2 mg/L standard. Use this standard to test the accuracy of the nitrate kit. Measure out 10 mL of the 100 mg/L standard nitrate solution using the 100 mL graduated cylinder. Pour this into the 500 mL flask or beaker. Measure out 490 mL of distilled water in the 500 mL graduated cylinder and add to 500 mL bottle or jar. Label with masking tape (include date). Carefully swirl the solution to mix the standard.
2. Follow the directions in the *Protocol* section to measure the standard. Where it says "sample water" this is where you use the standard that you made.
3. Record the value of the standard after testing on the Hydrology Investigation Data Work Sheet.
4. If the nitrate standard is off by more than 1 mg/L, prepare new dilutions and repeat the measurement. If still off, make a new stock solution and repeat the procedure.

How to Measure Nitrate Nitrogen

1. Use a nitrate measurement kit that meets the *GLOBE Instrument Specifications* in the *Toolkit*. Rinse the sample tubes in the kit at least 3 times with sample water before starting the measurement.
2. **Nitrate nitrogen plus nitrite nitrogen:** Follow the manufacturer's nitrate instructions in the kit. The kits are based on the technique of adding a reagent that reacts with nitrate to form nitrite. The nitrite reacts with a second reagent to form a color. The intensity of the color is proportional to the amount of nitrate in the sample. The concentration is determined by comparing the sample color, after addition of reagents, to a color comparator included in the kit. If the kit calls for shaking the sample, be sure to shake for the specified period of time.

Failure to follow the times specified in the directions will result in inaccurate measurements.

3. Have at least 3 students in the group read the color comparator. Record the nitrate concentration for each student group on the Hydrology Investigation Data Work Sheet. (**Note:** Hold the comparator up to a light source such as a window, the sky or a lamp. Do not hold it up to the sun.)
4. Take the average of the three readings. If the recorded values are all within 1 mg/L of the average, record the average on the Hydrology Investigation Data Work Sheet. If they are not within 1 mg/L of the average have the students reread the color comparator, then record and average the new values. (**Note:** do not reread if more than 5 minutes has elapsed.) If your remaining values are now all within 1 mg/L of the new average, record this new average on the Hydrology Investigation Data Work Sheet. If there is still one outlier (a value far different from the rest) discard that value and calculate a new average of the other values. If there is still wide scatter (more than 1 mg/L) in results, discuss the procedure and the potential sources of error with the students, but do not report a value to the Data Server. Repeat the protocol to produce a reportable measurement.
5. **Nitrite nitrogen:** Follow the manufacturer's instructions for nitrite. It is the same procedure, except the reagent to reduce nitrate to nitrite is not used.
6. Repeat steps 3 and 4 to obtain nitrite values.

Note: Test results should be reported as mg/L nitrate nitrogen (NO_3- N; the same units as your standards), and not as mg/L nitrate (NO_3^-).

For general information: To convert mg/L nitrate to mg/L nitrate nitrogen divide by 4.4, the ratio of their molecular weights. For example: 44 mg/L NO_3^- is equivalent to 10 mg/L NO_3-N. To convert mg/L nitrite to mg/L nitrite nitrogen divide by 3.3, the ratio of their molecular weights.

Learning Activities

Water Walk

Students become acquainted with their Hydrology Study Site and profile its characteristics.

Model Your Watershed

Students will combine their own local observations with a topographic map and satellite-derived imagery to construct a three-dimensional model of their watershed.

Water Detectives: (K-3)

Students will investigate how they use their senses for observation and why we use instruments to collect data.

pH Game

Students will play a game to better understand the importance of pH levels.

Practicing the Protocols

In the classroom, students practice using the instruments or kits for protocols, exploring the range of measurements and sources of variation and error.

Water,Water Everywhere. How Does It Compare?

Students will begin to look at and analyze GLOBE data with the Hydrology scientists.

Macroinvertebrate Discovery

Students will explore how the water chemistry affects life at their site.

Modeling Your Water Balance

Students will model the changes in soil water storage over a year.

Water Walk

Purpose

To become familiar with the hydrology of your locale

Overview

Students will visit the Hydrology Study Site, conduct a visual survey to discover information about local land use and water quality, and document their findings by mapping and profiling the water body. They will use this initial investigation to raise questions about local land use and/or water chemistry issues that may require further study.

Time

Field trip time plus one class period

Skill Level

All

Key Concepts

- Surface water exists in many forms, such as: ponds, lakes, rivers, and snow cover.
- Water characteristics are closely related to the characteristics of the surrounding land.
- Water moves from one location to another.
- Surface water has many observable characteristics, such as: color, smell, flow, and shape.

Skills

- *Observing* water at the study site
- *Describing* water at the study site
- *Organizing* observations
- *Asking* questions based on observations at the study site
- *Identifying* relationships between land characteristics and water characteristics
- *Communicating* initial observations and interpretations orally, in writing and graphically
- *Mapping* the hydrology of the study site

Materials and Tools

- Drawing materials and tools for creating pictures and maps
- GLOBE Science Notebooks and pens
- Still or video cameras for photography
- Compass and measuring sticks or twine
- Clear plastic cups or bottles for observing the clarity and color of the water

Preparation

Obtain topographic maps and satellite imagery of your study site.

Prerequisites

None

Background

Your body of water is part of a catchment basin. A watershed delineates a catchment basin, the area drained by a river and its tributaries. The topography of the area determines the shape of the watershed. The surrounding land and the uses of this land – towns, cities, highways, agricultural, livestock, timber harvesting, natural vegetation, etc.– influences the water chemistry of bodies of water within the watershed.

Many factors can affect the characteristics of the water in a river system, lake, or pond. Characteristics of water include: temperature, color, shape, etc. In the protocol, you will be collecting data about water quality as measured by dissolved oxygen, pH, alkalinity and electrical conductivity. Field observations increase the students' ability to conceptualize links between land characteristics and water characteristics. This activity is an introduction to your hydrology study site and lays the foundation for subsequent hydrology learning activities and the hydrology protocols.

What To Do and How To Do It

1. Ask students about their knowledge of local bodies of water. Begin with questions such as:
   Is there a lake, river, pond or stream that you visit?
   What is your favorite past-time at this place?
   Why is this body of water important to you?
2. Take your students to the Hydrology Study Site. Remind them of safety issues.

For beginning levels:

3. For the younger students, the goal is to, have the students walk around, observe and ask questions about the water in their study site. This includes noticing the flow of rivers or streams, the presence of ponds or lakes, residual water from precipitation, springs and soil moisture. Encourage your students to focus on water in all its forms as they walk around the study site. Take a container and collect a sample of the water. Ask students to observe the color of the water, what they see in the water, whether the water is moving and how fast, what is near the water, whether they can hear the water while they are quiet, whether the water has a smell, whether the water is clear or cloudy, etc.
4. Have your students draw pictures and/or take notes about the location and size of the study site. Compare the water location to other features on their study site such as trees, hills, etc. Have your students ask questions about where the water came from.

For intermediate and advanced levels:

3. Assign teams of students to survey different sections of the site. In teams composed of a journalist, a mapper, a sketcher, and a photographer, students should begin to document what they observe about their section. What is the appearance, smell, nature of the water in their section? Bordering lands should be noted: urban, agricultural, industrial, residential, wooded, swamp, etc. Students should map the general contours and characteristics of their sections and record the wildlife and plants in and around its water. What is the slope of the land adjacent to their section of water?
4. Back in the classroom, students should create a composite display of all the maps. Look for similarities and differences and discuss observed patterns. Based on their observations, encourage students to think about how the water got to this location, how it flows through the study site, where it goes from there, how the area surrounding the water influences the quality of the water particularly during periods of rain, snowmelt, flooding, etc. What questions do they have? Record them on a poster on the classroom wall.

Students at the University of Arizona performing pH, conductivity, and alkalinity measurements.

5. In addition, ask the students to discuss some of the following:

   What land use activities did you observe and list? How do you think these activities would change the water characteristics? Would these activities influence water quality?

   What type of water appearance was recorded most often and what might this indicate about the water quality?

   Was there evidence of human uses of the water? Evidence of wildlife and other animals using the water?

Further Investigations

1. As students visit the site monthly to collect data for the hydrology protocol, remind them of their observations during this activity and ask them to note changes in their GLOBE Science Notebooks.
2. The quantity and the quality of water is a global issue. Take your composite information about your Hydrology Site and prepare a written description of the features and characteristics, including such materials as graphs, of your hydrology data. Contact another school that has reported data and make arrangements to have them graph their hydrology data. Exchange and compare the graphs of the data from both schools. Each should then prepare a written description of the other's Hydrology Study Site based on the comparisons. Then exchange the written descriptions and discuss how the extrapolated descriptions compare with the original descriptions. Explore the things which can and cannot be concluded from the data.

Student Assessment

Have students create a visual display of what they know about their body of water, including surrounding land uses and their impacts on the quality of the water (both positive and negative) in ways that affect fish and animals, including humans, that depend on the water. Share this with others at school and in the community.

Acknowledgment

Adapted from The Aspen Global Change Institute's Ground Truth Studies Teacher Handbook, *River Walk*, and Project WET's *Stream Sense*.

Model Your Watershed

Purpose

To introduce students to their watershed and how it works

Overview

Beginning students construct a three-dimensional model of a watershed and experiment with water flow. Intermediate and advanced students use topographic maps and Landsat images to construct a three-dimensional model of their watershed and test hypotheses about water flow.

Time

For beginning levels: one class period

For intermediate and advanced levels: two to three class periods

Level

All

Key Concepts

A watershed guides all precipitation and run off to a common watercourse or body of water.

The Hydrology Study Site is part of a watershed.

The nature of a watershed is determined by the physical features of the land.

Skills

Modeling a watershed

Predicting water flow

Interpreting maps and images to create a physical model of the watershed

Materials and Tools

For beginning levels:

Plywood sheet approximately 1 m x 1 m

Rocks of various sizes

Plastic sheet

plant sprayer

For intermediate and advanced levels:

Topographic map of your Hydrology Study Site and surrounding area

Landsat image of your GLOBE Study Site (provided by GLOBE)

Plywood sheet approximately 1 m x 1 m

Plaster of Paris, clay or similar material

Waterproofing material or a household plastic wrap

Preparation

Gather the materials

Obtain topographical maps (refer to *How to Obtain Maps and Remote Sensed Images* in the *Toolkit*)

Prerequisites

For intermediate and advanced levels: basic understanding of maps and familiarity with topographic maps and Landsat images

For background information on contour maps, refer to Contour Line Basics in the *Appendix* to this investigation.

Background

The watershed guides all precipitation and runoff (water, sediment, and dissolved materials) to a common watercourse or body of water (catchment). A divide (or watershed) is the ridge between drainage areas. You may have heard of the Continental Divide, the ridge that divides the U.S. and causes all river systems east of it to flow to the Atlantic Ocean and all those west of it to drain to the Pacific Ocean. These large watersheds are made up of smaller ones. In this activity, students will locate their local watershed and create a model of it that will be useful as they study their water system.

Human activities, such as building dams to impound water, diverting water over divides from one watershed to another (transbasin diversion), or changing the topography of the land to build roads and other structures, can alter watersheds. Learning about and modeling a watershed is a way to help people grasp the realities of the water system on which they depend – where the water comes from, where it goes, and what kinds of choices people can make to use and conserve it responsibly.

What To Do and How To Do It

For beginning levels:

1. On the plywood board, place a variety of rocks of different shapes and sizes. Place a plastic sheet over the rocks, push down on the plastic around the rocks to give it shape and to ensure that there are high and low spots.
2. Ask your students what they think will happen when they pour water onto various places of this model.
3. Then, have your students use a plant sprayer to spray water over the surface of the model. Keep on spraying until the water flows. Observe how the water flows and where it collects.
4. Discuss with your students what they observed, paying special attention to how the shape of the model effects the flow of the water.
5. Ask your students what would happen if they move the rocks to different places. Ask them how they might arrange the rocks to have a more rapid, or slower flow of water or to have more or less water collect in a specific location.
6. Have your students rearrange the rocks to test their ideas. Repeat this variation several times.

For intermediate and advanced levels:

1. Ask students:
   What is a watershed?
   Why are watersheds important?
2. Provide students with topographic maps and Landsat images of your area. Help the students to get oriented to what is shown in the topographic map and in the Landsat image and how to correlate the two. Assist the students in using the satellite-derived imagery as a similarly-useful resource. Ask the students to identify their watershed with a name, and find its boundaries. Contour lines and elevation changes on the topographic map are helpful in establishing watersheds. By marking hilltops and ridges, students can create a useful outline of their watershed.

   To begin, students should select an easily identifiable point, such as the mouth of a stream. Working backwards from that point, they should mark other obvious points like peaks and ridges that separate adjacent streams. Ask, "Which way would the water flow from this point?" Have students draw arrows to show drainage patterns. The picture of the watershed will become clearer as more points are identified.
3. Provide students with the materials to build a model of their watershed using one of a number of different media. Plaster of Paris, clay, and/or other materials of your choice will work well. Ask the students to work in small groups to create their model. They should cover the model with household plastic wrap.
4. Once completed, ask the students to spray water on the model and trace the path a drop of water takes across the watershed and into the watercourse.
5. Discuss the relationship between the physical features of the watershed and the location of human activities. Focus especially on the patterns of the flow of water in your watershed.

Further Investigations

1. What larger watershed is your watershed a part of? And which watershed is that larger one a part of? Keep asking yourself this question for larger and larger watersheds. What is the largest watershed of all?
2. Compare recent satellite-derived images with those from earlier time periods. What changes have taken place in the watershed?

Student Assessment

1. Ask students to write an essay about the importance of watersheds.
2. Ask the students to describe how each of the Hydrology protocols is relevant to understanding watersheds and their significance.
3. Have students locate several natural physical features and several human-made features on the topographic map, and satellite images. Locate their corresponding positions on the watershed model.
4. Ask students to describe ways in which the physical features of the watershed could influence future human activities. Let them predict ways physical features of the watershed could influence future human activities.
5. Ask students to describe ways in which human activities change the shape of the watershed, and, consequently, the path along which water will flow.

Acknowledgment

Adapted from *Make A Watershed Model* (Aspen Global Change Institute's Ground Truth Studies Teacher Handbook), with additional information from *Understanding Watersheds* from Tennessee Valley Authority.

Water Detectives

Purpose

To help students understand that there are many substances in the water which they can find using their senses and that there are other substances which they can only identify using tools

Overview

Students will try to identify substances in the water using their five senses. They will then use GLOBE instruments to detect substances in the water.

Time

One class period

Level

Beginning

Key Concepts

Your 5 senses tell you about the world.
Your senses detect different things.
You use tools to help enhance your senses.

Skills

Exploring answers to questions
Developing answers to questions (hypotheses)
Conducting an experiment
Making observations
Recording data
Counting (or adding)

Materials and Tools

For each team of 4 or 5 students:

- 5 clear plastic cups or jars
- 5 plastic spoons
- Marker to number cups
- Items to detect in the water which represent all of the senses, such as:
  - Sight - drop of yellow food coloring, lemon juice, carbonated water
  - Touch - baking soda
  - Smell - lemon juice, vinegar
  - Taste* - salt, sugar, distilled water, tap water
  - Hearing - carbonated water
- Work Sheet
  - * Use of taste is at the discretion of the teacher.

Preparation

Prepare the water samples for the experiment and duplicate the Water Detectives Work Sheet.

Prerequisites

None

Background

With an average runoff of 30 cm/yr, the hydrologic cycle constantly erodes the continents. A fraction of the eroded material is transported by rivers to oceans, both as suspended solids (e.g. sand, clays, and silts) and dissolved substances (e.g. salts). These can be considered as natural pollutants and can vary from dissolved limestone (calcium carbonate) to dissolved minerals that contain heavy metals such as lead, cadmium, and zinc. Other substances are introduced into the hydrologic system through human activity. Oil, sewage, and chemical fertilizers and pesticides are examples. It is clear that if materials are being carried in the water, all forms of life using that water are subject to the effects of these substances.

Scientists have developed tests to see if various substances, whether harmful or beneficial, naturally occurring or not, are found in water. These tests involve the use of tools to measure substances or properties that humans can not sense directly.

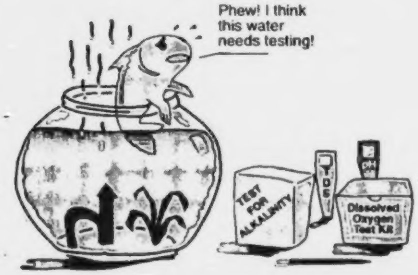
Preparation:

- Provide a work station with cups of water with small amounts of each 'mystery food' substance mixed in for each group (saltwater, carbonated water, etc.). Also provide tap water among the testing cups.
- Lay out spoons for dipping water to feel and to taste.
- Number the cups with the marker.
- Copy the Work Sheet for each student.

What to Do and How to Do It:

Discuss with students how they use their senses to detect things in their environment. Discuss the advantages and limitations of each of the senses. Questions students may want to think about:

1. How do we use our eyes to detect danger? When does our sense of sight not work very well? *(when something is out of vision range, in the dark, invisible...)*
2. How do we use our ears to detect danger? When do our ears not work very well? *(things that make no sound, when we do not listen or pay attention...)*
3. How do we use our sense of smell to detect danger? When does it not work very well? *(some things are odorless, when we have a cold...)*
4. How do we use our sense of touch to detect danger? When does it not work very well? *(when an object is far away, when touching might be dangerous...)*
5. How do we use our sense of taste to detect danger? When does it not work very well? *(when something might be poisonous or unclean...)*
6. Hold up a cup of water. Ask, which of your senses do you think would be most useful for finding out if the water was tap water for drinking? Consider the advantages and disadvantages of using each of your senses.
7. Do you think that just one of your senses would always work for finding out which of the cups contained tap water? Make a guess (hypothesis) as to which of your senses would most often detect mystery foods in the water. On your Water Detectives Work Sheet circle your guess from the pictures at the top of the paper.


Phew! I think this water needs testing!
TEST FOR ALKALINITY
TDS
pH
Dissolved Oxygen Test Kit

Doing the Experiment

1. Show students the boxes of 'mystery food' which have been put in the water (salt, baking soda, etc.) Say, "These are foods that I have mixed into the water in front of you. We are going to use our senses to detect which of these foods are in the cups."
2. Have students look at the cups of water. Have them make an X on the Work Sheet next to the number of any cup that does not look like tap water. Put a W next to any cup that does look like tap water.
3. Have students listen to the cups of water. Have them make an X on the Work Sheet next to the number of any cup that does not sound like tap water. Put a W next to any cup that does sound like a cup of water.
4. Have students smell each cup of water. Have them make an X on the Work Sheet beside the number of any cup that does not smell like tap water. Put a W next to the cups that do smell like tap water.
5. Have students dip a few drops of water from each cup with the spoon to feel the water. Have them put an X on the Work

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Sheet next to any cup that does not feel like tap water. Put a W next to any cup that does feel like tap water.

6. Have students dip a spoon in each cup of water to taste it. Tell them to use a clean spoon each time. Have them put an X on the Work Sheet next to the cups that taste different than tap water. Put a W next to any cup that does taste like tap water.
7. Have students count the number of X's under each sense. Which sense had the most X's? This is the sense that was best for detecting what was in the water.
8. Have students review which senses they thought were best for exploring water. Taste? Remind students that it was OK to taste the water today, but ask, "Would you want to taste water if you didn't know anything about what was in it?
9. Ask students what other ways might be used to find out what was in water. Introduce the idea of how we use tools and ask for examples of how we use tools to help our senses. For example, they may think of smoke detectors, microscopes, hearing aids, etc.
10. Introduce students to pH paper as a tool for sensing water. Have students use pH paper to test their cups of water. What can the pH paper detect?

Note: A follow-up activity for pH is the pH Game. Students can explore different pH values of different substances found in their environment.

Adaptation for Older Students:

1. Have students use more advanced tests to determine differences in the water (alkalinity, conductivity, salinity or specific gravity).
2. Challenge students to devise their own tests for detecting differences in the water. (Example: shaking the water, adding other chemicals which might react with things in the water.)

Student Assessment

Ask students to:

- list several substances found in water
- explain why instruments are sometimes needed to detect substances
- guess (hypothesize) how various substances might affect things living in the water
- explain how each sense is good for examining different kinds of materials
- use the Work Sheet to record their (data) information and see how the work sheet can help them explain the results.

Further Investigations

Have students investigate whether different plants and animals like different types of water.

Water Detectives Work Sheet

*Name:*________________________________

Cup	See	Hear	Smell	Feel	Taste	pH Test
	👁	👂♫	👃✿	👉	👄	
1 one						
2 two						
3 three						
4 four						
5 five						
TOTAL						

Directions for Filling Out the Form

Under the column for each sense and in the row for each numbered cup, put an "X" in each box that represents a liquid that you think is NOT water. Put a "W" in the box that represents the liquid that you think IS water.

Be sure that you use only the sense that is listed in each column when making your decision. When you are done testing each sense for each cup look at the rows to see which one has the most W's. That should be the cup with the water.

The pH Game

Purpose

To teach students about the acidity levels of liquids and other substances around their school so that they understand what pH levels tell us about the environment

Overview

The pH game will engage students in the measurement of the pH of water samples, soil samples, plants and other natural materials from different places. Students will create mixtures of materials in order to collect different pH measurements.

Time

One class period for preparation

One class period for the game

Level

All

Key Concepts

pH measurements

Skills

Taking measurements
Conducting analysis
Interpreting findings
Understanding interrelations in nature

Materials and Tools

For each team (about 4 students):
- 20 pH strips
- 3 or 5 small cups
- Paper and pencil
- Labels with which to attach results to the results board

For the whole classroom:
- Results board for all teams (one line of pH levels from 2 to 9 for each team)
- Flip chart with rules
- Additional pH strips

Preparation

The teacher should prepare various acidic and alkaline mixtures/solutions of natural and processed materials. These solution should be labeled with the ingredients and a letter, but not their acidic or alkaline characteristic. Examples of acidic solutions include fermented grass, dilute and concentrated lemon juice, black coffee, vinegar, orange juice, and soft drinks. Alkaline solutions include salt water, shampoo, baking soda, chlorine bleach, household ammonia, and oven cleaner. Soil solutions produced by mixing water and local soil samples should be used as well as local water samples. The teacher can also produce solutions from materials found around the local school area, such as oil drippings from a vehicle, liquid in a discarded bottle, etc.

Prerequisites

None

Background

The level of acidity (pH) significantly influences the vegetation and wildlife in an environment. The pH can be influenced by different factors. The main influences are the alkaline contributions from rocks and soils, the amount of water in the landscape and also human activities (traffic, buildings, paved surfaces, etc.). Acid rain may also have an important impact on water pH. It is important to understand these relationships. This simple activity will help your students to understand the interdependence of nature and human activities.

Note: Remind students of the difference between hypothesis and results. Encourage them to develop their hypothesis and find a way to test it with results (prepare some literature for them, invite an expert to the class, examine past measurements, etc.).

The Rules

1. Explain to students the objective of the game is that each team identifies solutions which have a pH range of 2-9.

   The students should draw a horizontal pH scale line from 0 to 14, marking pH 7 as the neutral point. Each unit should be spaced at least 1 cm apart. They should then draw a box underneath each pH unit from 2 to 9.

   Each team finds substances that have a pH corresponding to a box in the pH scale.
2. The teacher draws the following matrix on the board. See Matrix HYD-L-1.
3. One point is awarded for each box filled, even if the team finds two samples with the same pH.
4. Students should record all the information about the solution from the labels and the pH they measured.
5. When students are ready to submit a sample for the game results board, they show the teacher their notes and sample. Together they measure the pH with a new pH strip. If the pH agrees with the students' previous measurement, the sample is approved and the points are added to the team's score. The table below is an example of results for different teams. See Matrix HYD-L-2.
6. The teacher gives a new pH strip for each sample added to the results board.

Matrix HYD-L-1

	pH Value								
Teams	2	3	4	5	6	7	8	9	TOTAL
Team 1									
Team 2									
Team 3									

Matrix HYD-L-2

	pH Value								
Teams	2	3	4	5	6	7	8	9	TOTAL
Team 1	1		1			1	1		4
Team 2		1		1				1	3
Team 3	1				1		1		3

Modifications for different ages

Beginning

For a basic understanding, use salt and sugar and explain to students that salty does not necessarily mean acid and that sweet does not necessarily mean alkaline. Cola soft drinks are good examples of a sweet and very acid liquid.

Intermediate

Make the game more competitive. For instance, the team that finds or creates the first sample of a particular pH value receives 5 points; subsequently, samples for that pH level receive only 1 point.

Make the game more difficult by limiting the sample sources to only natural materials.

Limit the number of pH strips given to each group and set up a rule for buying a new one with game points.

Advanced

Ask the students which solutions should be added together to produce a neutral solution. Have them test their hypothesis by adding some of the labeled solutions together and recording the pH. Have students quantify the neutralization capacity of different solutions. Relate this to buffering capacity (alkalinity) of hydrology sites.

Provide students with samples of solutions from other parts of your country (or of the world) and ask them to characterize how they influence pH differently.

Conduct a similar analysis of samples from different geological layers or different areas of the community or study site.

Note: For older students we recommend inviting an expert to answer their questions.

Further Investigations

Examine the Hydrology Study Site for materials in soil, rocks, and vegetation that influence the pH of the water.

Try to identify and quantify influences that are not always present at the study site, such as precipitation or some event upstream of your sampling site.

Student Assessment

After the game sit with students around the results board and identify what samples they have found, where the samples were found, and the pH of the samples. Encourage students to present their own ideas about why different samples have different pH values. Emphasize differences among water samples from soils, rocks, artificial surfaces, lakes, rivers, etc. Mention the acid neutralization capacities (alkalinity) of some rocks and the acidic influences of different materials. Ask them why it was difficult to find samples for some pH levels and easy to find others.

Acknowledgments

The pH game was created and tested by the leaders team of TEREZA, the Association for Environmental Education, Czech Republic.

Practicing the Protocols

Purpose

To have students:

1. learn how to use each of the hydrology instruments correctly
2. explore the ranges of measurements possible with each instrument
3. use each instrument as directed in the protocol
4. understand the importance of quality control.

Overview

Groups of students will rotate among measurement stations for each of the protocols that will be performed by the class. They will practice using the instrument or kit and protocol for that particular measurement, exploring sources of variation and error. The activity concludes with students testing water samples brought from a variety of places (home, yard, puddles, brooks, etc.).

If you have enough instruments and kits, you may want to focus on a subset of the measurements during a given class period in order to simplify the discussion.

Time

Three to four class periods

Level

Varies with the protocol

Key Concepts

Quality assurance
Quality control
Reliability
Accuracy
Protocol
Calibration

Skills

Following directions carefully
Performing measurements

Materials and Tools

Refer to the *Hydrology Protocols* for the instruments, equipment and kits required for each protocol.

One bucket of tap water

Copies of Hydrology Investigation Student Activity Sheets

In addition you will need the following materials for particular protocols:

Transparency: green food color, spoonful of silt
pH: samples of vinegar water, distilled water, milk, juice, soda pop, etc.
Temperature: ice
Conductivity: distilled water, salt
Salinity: distilled water, salt, ice
Nitrate: lawn fertilizer

Preparation

Ask students to bring in water samples from the home and/or yard.

Set up measurement stations for each of the protocols your students will be performing. For each station you will need:

Equipment and instruments to perform the measurement

One copy of the protocol to be posted at the station

Copies of the Hydrology Investigation Student Activity Sheet.

Draw a bucket of tap water at the beginning of the day and allow it to sit until class. Record the time on a piece of tape attached to the bucket.

Fill a Dissolved Oxygen sample bottle at the same time and preserve the sample as directed in the protocol. Record the time on the sample bottle label.

Prerequisites

None

Background

A quality assurance and quality control (QA/QC) plan is necessary to ensure test results are as accurate and precise as possible. Accuracy refers to how close a measurement is to true value. Precision means the ability to obtain consistent results. Desired accuracy, precision and reliability are ensured by:

careful calibration, use, and maintenance of testing equipment
following the specific directions of a protocol exactly as described
repeating measurements to ensure that they are within acceptable limits
minimizing contamination of samples, stock chemicals and testing equipment
keeping track of samples.

Together these steps help make the data you collect valid, valuable and meaningful.

Calibration

Calibration is a procedure used to check the accuracy of testing equipment. To assure that the equipment is functioning properly, a solution of known value is tested. Calibration procedures vary among the measurements and are detailed in each protocol.

Safety

Consult Material Science Data (MSDS) sheets that come with the kits and buffers. Also consult your local school district's safety procedure guidelines.

What To Do and How To Do It

1. Divide the students into small groups, optimally three per group. Checking each others work, students should take turns reading directions, making measurements, and recording the data.
2. Students rotate through each station learning the instruments and protocols.
3. Reconvene the class. For each measurement:
   3.1. Plot all the data points as a way of helping students visualize the concept of precision. When measurements are precise, points are close together. Discuss the range of measurements found and variations among the measurements.
   3.2. Brainstorm with students the issue of why there are discrepancies. This is the time to bring up calibration against standards, reliability, accuracy, and adherence to protocols. Connect explanations with reasons for specific steps in the protocols. Stress the importance of making accurate measurements so they can compare different samples.
4. Compare the results they obtained on samples from various places. Help them make sense of their results by placing data on a map of the water sources and considering the history of each sample in terms of well water, city water, pool, pond, puddle or brook. This is also a good time to stress the importance of accurate measurements when you make comparisons. Is the difference real or measurement error? This is also the time to discuss why we didn't test these samples for DO and temperature and how we might test for them.

Adaptations

Beginning students

Focus on one measurement at a time, following the outline given above.

Advanced students

Have students create their own data plots and interpret them.

Further Investigations

Repeat the above explorations but vary one parameter-such as temperature by cooling one third of each water sample, and heating one third of the water samples, with the remaining one third at room temperature. Then compare the effect of water temperature on the other measurements.

Hydrology Investigation
Student Activity Sheet

Transparency Station

Background

Transparency is the measurement of water clarity. How clear the water is at your site will depend on the amount of soil particles suspended in the water and on the amount of algae or other growth at your site. Transparency may change seasonally with changes in growth rates, in response to precipitation runoff, or for other reasons. The clarity of your water determines how much light can penetrate. Since plants require light, transparency becomes an important measurement in determining productivity of your water site.

In the field you would measure transparency in one of two ways; with a Secchi disk in deep, still waters or with a turbidity tube if your site has shallow or running water. For the lab practice station, we will use the turbidity tube.

What To Do and How to Do It

1. Ask each student to fill the turbidity tube with tap water until the image disappears. Record the depth of the water in the tube in cm.
2. Compare data from several students. Ask students to formulate hypotheses on variations in their data.
3. Try the tube again testing variables such as: amount of light in the room, tube in sunlight and shadow, with and without sunglasses, turning the tube to try and detect the image at the bottom, letting the water stand in the tube for 15-20 seconds.
4. Once students have established the depth using tap water, pour the water into a bucket and mix a few grams of silt into the water.
5. Ask students to fill the turbidity tube with the silty water until the image disappears. Record the depth of the water in the tube in cm. Compare the readings from several students.
6. Put a few drops of green food coloring in tap water.
7. Have each student fill the turbidity tube with colored water until the image disappears.

Student	Sample Tested	cm

Hydrology Investigation

Student Activity Sheet

Temperature Station

Background

Water temperature is the temperature of a body of water such as a stream, river, pond, lake, well, or drainage ditch as it appears in nature. Water bodies can vary greatly in temperature, according to latitude, altitude, time of day, season, depth of water, and many other variables. Water temperature is important because it plays a key role in chemical, biological and physical interactions within a body of water. For example, high temperatures may be an indicator of increased plant production. The temperature of the water determines what aquatic plants and animals may be present since all species have their natural limits of tolerance to upper and lower temperatures. Water temperature can therefore help us to understand what may be happening within the water body without directly measuring hundreds of different things within the body of water.

What To Do and How To Do It

1. Following the steps in the *Water Temperature Protocol*, each member of the group should take a turn measuring the temperature of the same sample with the same thermometer. Make sure everyone in the group can read the thermometer. Compare your readings. Are they within 0.5° C of each other? Why? Why not? If not, repeat this exercise with another water sample until you are obtaining readings within 0.5° C of each other.
2. With each member of the team using a different thermometer and following the steps of the water temperature protocol, measure the temperature of a single water sample and compare your readings. Do you get readings within 0.5° C of each other? Why? Why not? If not, your thermometers may need calibration.
3. Following the steps in the water temperature protocol, measure the temperatures of water from the hot and cold water taps, ice water, and the water that has been standing in the bucket. List the things you checked and record the temperatures you obtained for them.
4. Discuss the range of measurements possible with each of the thermometers. Can you take temperatures below the freezing mark? Why? Why not? Can you take the temperature of boiling water with the thermometer provided? Why? Why not?

Student	Sample Tested	Temperature

Hydrology Investigation
Student Activity Sheet

Dissolved Oxygen Station

Background

All living things depend on oxygen to survive. In a water environment molecules of oxygen gas dissolve in the water. This is called dissolved oxygen (DO). In air, 20 out of every 100 molecules are oxygen. In water, only 1-5 molecules out of every million molecules are oxygen. This is why dissolved oxygen is measured in parts per million (ppm). Different species of aquatic organisms require different amounts of oxygen, but generally aquatic organisms require at least 6 ppm for normal growth and development.

Water temperature and altitude influence how much oxygen water can hold; i.e., the "equilibrium" value. In general, warmer water cannot hold as much oxygen as colder water. Similarly, at higher altitudes water cannot hold as much oxygen as waters at lower altitudes. Look for these patterns in the Temperature and Altitude Tables in the DO protocol. This is why we use a distilled water standard in the protocol and correct for temperature and altitude.

The actual amount of DO in a water may be higher or lower than the equilibrium value. Bacteria in the water consume oxygen as they digest decaying plant or animal materials. This can lower the DO levels of the water. In contrast, algae in lakes produce oxygen during photosynthesis which can sometimes result in higher DO levels in summer.

What To Do and How To Do It

1. Following the steps in the *Dissolved Oxygen Protocol*, each member of the group takes a turn measuring the DO of the same sample. Compare your readings. Are they within 0.2 mg/L of each other? Why? Why not? If not, repeat this exercise with another water sample until you obtain readings within 0.2 mg/L of each other.
2. If your water faucets have aerators on them, test a water sample freshly drawn from the faucet, one that was drawn at the beginning of the day and allowed to sit undisturbed in a bucket, and the preserved sample drawn at the same time. Record the time at which you tested the water in the bucket. How long has it been since the water was drawn? Compare the readings. Are they different? Why? Why not? What might account for the differences?

Student	Sample tested	Time	DO

Hydrology Investigation
Student Activity Sheet

pH Station

Background

pH is an indicator of the acid content of water. The pH scale ranges from 1 (acid) to 14 (alkaline or basic) with 7 as neutral. The scale is logarithmic so a change of one pH unit means a tenfold change in acid or alkaline concentration. For instance, a change from 7 to 6 represents a solution 10 times more acidic; a change from 7 to 5 is 100 times more acidic, and so on. The lower the pH the more acidic the water. The pH of a water body has a strong influence on what can live in it. Immature forms of salamanders, frogs, and other aquatic life are particularly sensitive to low pH.

What To Do and How To Do It

1. Following the steps for pH paper in the *pH Protocol*, each member of the group takes a turn measuring the pH of the same sample. Compare your readings. Are they within 1.0 pH units of each other? Why? Why not? If not, repeat this exercise with another water sample until you are obtaining readings within 1.0 pH units of each other.
2. Without calibrating the pH pen, but following the steps for the pen given in the *pH Protocol*, take turns measuring the pH of a different water sample. Record these numbers.
3. Calibrate the pH pen and repeat the measurements again following the protocol carefully to avoid contaminating samples. Alternatively, students could use one calibrated pen and one that has not been calibrated if there is enough equipment. Record your readings.
4. Compare the data obtained using different methods. Discuss possible reasons for the differences.
5. Take the pH of familiar liquids such as distilled water, vinegar, tap water, milk, juice, soda pop, etc. using pH paper, uncalibrated pH pens, and calibrated pH pens.
6. List the samples you checked and record the pH obtained by the different methods. Which methods gave the most accurate results? The most reliable?
7. Create a pH scale and plot the average values obtained for each sample.

Sample tested	pH paper	uncalibrated pH pen	calibrated pH pen

Hydrology Investigation

Student Activity Sheet

Electrical Conductivity Station

Background

Electrical conductivity is a measure of the ability of a water sample to carry an electrical current. Pure water is a poor conductor of electricity. It is the impurities in water, such as dissolved salts, that enable water to conduct electricity. Therefore, conductivity is often used to estimate the amount of dissolved solids in the water since it is much easier than evaporating all the water molecules from a sample and weighing the solids that remain.

Conductance is measured in a unit called the microSiemen/cm. Sensitive plants can be damaged if they are watered with water that has electrical conductivity levels above about 2200-2600 microSiemens. For household use, we prefer water with conductivity below 1100 microSiemens. Manufacturing, especially of electronics, requires pure water.

What To Do and How To Do It

1. Following the steps in the *Electrical Conductivity Protocol*, each member of the group takes a turn measuring the conductivity of the same tap water sample. Compare your readings. Are they within 40 µSiemens/cm of each other? Why? Why not? If not, repeat this exercise with another water sample until you are obtaining readings within 40 µSiemens/cm of each other.
2. Without calibrating the electrical conductivity pen, but following the steps of the protocol, take turns measuring the conductivity of distilled water, tap water, and distilled water to which you have added a pinch of salt. Record those numbers.
3. Calibrate the pen and repeat the measurements following the protocol carefully to avoid contaminating samples. Record your readings below.
4. Compare the data obtained using the uncalibrated pen and the calibrated pen. Is there a difference? Discuss possible reasons for the differences. Is one pen always higher or lower than the other? By the same amount?
5. Measure the conductivity of familiar liquids such as vinegar, drinking water, milk, juice, soda pop, etc.

   List the samples you checked and record the results.
6. What is the range of conductivity readings? Create a conductivity scale and plot the value obtained for each sample.

Sample tested	uncalibrated conductivity pen	calibrated conductivity pen
distilled water		
tap water		
salty water		

Hydrology Investigation

Student Activity Sheet

Salinity Station - for Salt or Brackish Water

Background

Salinity is the measurement of dissolved salts in salty or brackish water. It is measured in parts per thousand (ppt). Salinity may vary with precipitation, snow melt, or proximity to a freshwater source such as a river mouth.

The hydrometer is an instrument which measures the specific gravity or density of a fluid. Its design is based on the principle, recognized by the Greek mathematician Archimedes, that states that the weight loss of a body in a liquid equals the weight of the liquid displaced. The denser your liquid, therefore, the less the weighted bulb must sink to displace its own weight.

Why do you need to take a temperature reading with your hydrometer reading? Water becomes more dense as it approaches freezing - then less dense as it becomes ice. Since we want to measure the effect of dissolved salts on density, we must control the temperature variable.

What To Do and How To Do It

1. Fill a 500 mL cylinder with fresh water to the 500 mL line.
2. Gently place the hydrometer into the cylinder (do not drop).
3. Read the scale on the hydrometer at the bottom of the meniscus. Record.
4. Remove the hydrometer and add 7.5 grams of salt to the cylinder. Stir.
5. Use a thermometer to measure the temperature in the cylinder 10 cm below the surface. Record.
6. Use the hydrometer to measure the density of the fluid in the cylinder. Record.
7. Look up the salinity of your fluid from the table using the temperature and hydrometer readings. Record.
8. Add 10 grams of salt to your mixture.
9. Measure the temperature and salinity of the fluid. Record.
10. Add a few pieces of ice to the cylinder.
11. Measure the temperature and salinity of the fluid. Record.

Examine the data which you have recorded. The salinity of fresh water should be 0. As you add salt to the water, the salinity should increase. Changing the temperature will affect the density of the water, but should not affect the salinity after the conversion is done.

Discuss any variations between students. Repeat the measurements if variations exceed 2 ppt.

Work Sheet for Salinity Station

Sample	Temperature	Hydrometer	Salinity	Student/s
Fresh water				
7.5 grams salt				
17.5 grams salt				

Hydrology Investigation

Student Activity Sheet

Alkalinity Station

Background

Alkalinity is a measure of the ability of a body of water to resist changes in pH when acids are added. Acid additions generally come from rain or snow, although soil sources may also be important in some areas. Alkalinity is generated when water dissolves rocks such as calcite and limestone. The alkalinity of natural waters protects fish and other aquatic organisms from sudden changes in pH.

What To Do and How To Do It

1. Following the steps in the *Alkalinity Protocol*, each member of the group takes a turn measuring the alkalinity of the same sample of tap water. Compare your results. Are they within one drop or titrator unit of each other? Why? Why not? If not, repeat this exercise with another tap water sample until you are obtaining results within one drop or titrator unit.
2. Test the water samples you have brought to class from other sources.
   List the source of the water sample and the results obtained. Compare the alkalinity of these samples. What is the range of results? Why are there variations?

Student	Sample tested	Reading

Hydrology Investigation
Student Activity Sheet

Nitrate Station

Background

Nitrogen is one of the three major nutrients needed by plants. Most plants cannot use nitrogen in its molecular form (N_2). In aquatic ecosystems blue-green algae are able to convert N_2 into ammonia (NH_3) and nitrate (NO_3^-) which can then be used by plants. Animals eat these plants to obtain nitrogen that they need to form proteins. When the plants and animals die, protein molecules are broken down by bacteria into ammonia. Other bacteria then oxidize the ammonia into nitrites (NO_2^-) and nitrates (NO_3^-). Under suboxic conditions nitrates can then be transformed by other bacteria into ammonia (NH3), beginning the nitrogen cycle again.

Typically nitrogen levels in natural waters are low (below 1 ppm nitrate nitrogen). Nitrogen released by decomposing animal excretions, dead plants, and animals is rapidly consumed by plants. In water bodies with high nitrogen levels eutrophication can occur. Nitrogen levels can become elevated from natural or human-related activities. Ducks and geese contribute heavily to nitrogen in the water where they are found. Man-made sources of nitrogen include sewage dumped into rivers, fertilizer washed into streams or leached into groundwater, and runoff from feedlots and barnyards.

Nitrate levels are measured in milligrams per liter nitrate nitrogen.

What To Do and How To Do It

1. Following the steps in the *Nitrate Protocol*, measure the nitrate level of the water sample. Compare the readings of several students. Are they within 0.2 mg/L of each other? If not, discuss possible reasons for error. Repeat the readings until you obtain readings within 0.2 mg/L.
2. Repeat the protocol with the same water, but shake the sample for half of the time given in the protocol.
3. Repeat the protocol with the same water, but leave the sample to set for five minutes beyond the time given in the protocol.
4. Measure the nitrate level in a number of different water samples: runoff from a golf course, other pond water, a stock tank, river, etc. List the sources of water and record your results.
5. Add a few grains of fertilizer to your sample. Test again. What is the difference?
6. Discuss possible sources of nitrogen in your water samples.

Sample Tested	Reading	Student

Water, Water Everywhere! How Does It Compare?

Purpose

To see how water characteristics can vary with location and to encourage students to see how other sites compare to theirs. To illustrate to students how scientists are beginning to explore their data and to encourage students to begin their own data analyses.

Overview

Students will be asked to examine initial student data which scientists have identified from the GLOBE data set. After reading the scientist's comments about the data, students will then be asked to find additional data from GLOBE schools to explore and analyze.

Time

One class period for the initial activity and ongoing for follow-up

Level

Intermediate and Advanced

Key Concepts

Water characteristics vary (within some limits).

Data are used to pose questions.

Data are used to answer questions.

Skills

Graphing data

Making comparisons over space and time

Analyzing data for trends and differences

Forming hypotheses

Testing hypotheses

Using the GLOBE database

Materials and Tools

Pencil and graph paper, or computer tools

Computer and the GLOBE Student Server

GLOBE Science Notebooks

Preparation

Collect GLOBE data.

Prerequisites

None

Background

Although it sometimes takes many years to develop a data set to explore or answer questions about a site, GLOBE scientists have already begun to examine the growing set of GLOBE Hydrology data to get early indications of interesting trends and to monitor data quality. To help students begin to examine their own data and data from other schools, the GLOBE hydrologists want to share their preliminary investigations with you. Below you will find the early results from the analysis of pH and temperature data, as well as some interesting questions posed by examining other hydrology data. Since these investigations are ongoing, there will be updates as new data come in. These will be posted on the GLOBE Student Data Server at the Scientist's Corner. You can also find additional information on regional analyses on the WEB pages.

As more and more data become available in the archive, scientists will be continuing their efforts to look for interesting trends and to ask more questions. Students can assist in this effort by monitoring and analyzing the data over time from their own sites as well as from other sites around the globe and sharing their ideas and research with others in the GLOBE network.

What To Do and How To Do It

Section 1 of this activity contains a series of graphs that have been generated from GLOBE data on pH and temperature. These were chosen to illustrate particular questions commonly posed by students or data quality problems commonly observed by scientists. Each set of graphs can be used as a starting point for further investigations or discussion of data analysis.

Begin by showing students the graph of 'typical' pH data and temperature readings. Discuss expected trends in data sets and encourage questions or comments on the data.

Then, with each of the following sets of graphs have students examine the data and pose hypotheses or ask questions about what they are observing. Record their observations. Once your students have examined the graphs and recorded their observations and hypotheses, compare their conclusions with what the scientists think may be happening. These recordings should be done in the students' GLOBE Science Notebooks. Students may then move on to the Further Investigations to analyze their own data or data from other sites.

In Section 2, GLOBE scientists have begun the initial examination of the newer GLOBE protocols: dissolved oxygen, alkalinity, and conductivity. Students can examine our graphs, then try to identify trends and problems with the new data measurements.

The graphs below can also be found on the WEB in the Scientist's Corner. Teachers may use these in print form, make overheads, or have students work at computer stations. In addition, more graphs and information on further research by GLOBE scientists are available on the WEB and can be downloaded for printing or used on the computer. **Note:** Copies of the graphs included in the activity are available in larger format in the *Appendix*. These can be used to make overheads for instruction or for duplication and distribution to students for analysis or assessment.

What is an example of a typical GLOBE data set?

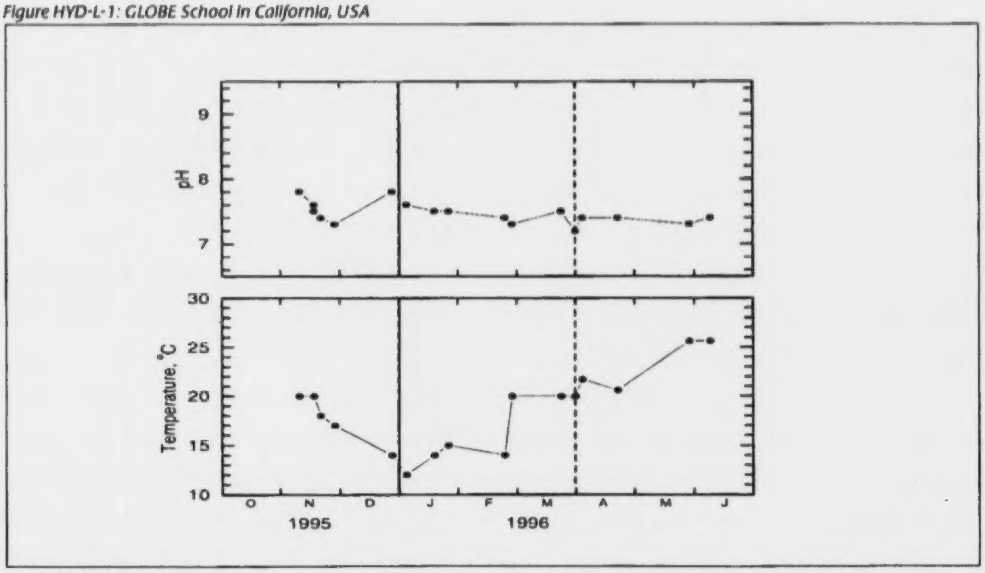
Typical characteristics

- pH data go up and down, but within a reasonable range.
- Temperature jumps around a little, but follows a seasonal trend.

Are there unusual things even in this data set?

Sure there are! Take a second look and think about the graphs in Figure HYD-L-1. Do you see anything surprising? Look at the jump up in pH from November to December! It could be a result of testing methods, but it might also be real! If

Figure HYD-L-1: GLOBE School in California, USA



equipment has been calibrated and multiple testing has shown the same result, these students should be trying to identify other factors which might cause an increase.

Section 1 - pH and Temperature Data

Part 1 - Identifying Outliers

1. Show students the graphs in Figures HYD-L-2 and HYD-L-3. After they have had an opportunity to examine the graphs and record their observations, ask them to identify any unusual data points.
2. Discuss the importance of data quality. Ask students what they should do if some data points are far beyond the range of the rest of the set (are they outliers)?
3. Discuss their observations and recommendations.

Note from the scientists

We have plotted all of the data as time series graphs. Before we can discern trends and compare data from different sites, we go through the data carefully looking for outliers. For example, notice in Figure HYD-L-2 that one temperature reading lies outside the range of the others. This is probably an error, and we will remove this point from our analysis before continuing.

In addition, pH readings that deviate significantly from the average are suspect. For Figure HYD-L-3, note the single pH 4 reading, with the rest of the pH's being in the 6-9.5 range.

Some additional items of interest can be seen looking at these graphs. Figure HYD-L-3 shows what appears to be a pH trend gradually climbing over the course of the record. The pH's seem to be more scattered than would be expected. Why do you suppose this is the case? In Figure HYD-L-2, we see a more typical variation in pH values, with a gradually increasing trend. This might be a problem associated with a buffer solution that was losing its accuracy, or it might actually represent a real pattern in nature!

Further Analysis

Encourage students to look at their own data. Time series graphs may be generated by importing GLOBE data into a spreadsheet, or by using the new GLOBE graphing tools to graph student data.

Figure HYD-L-2: GLOBE School in California, USA

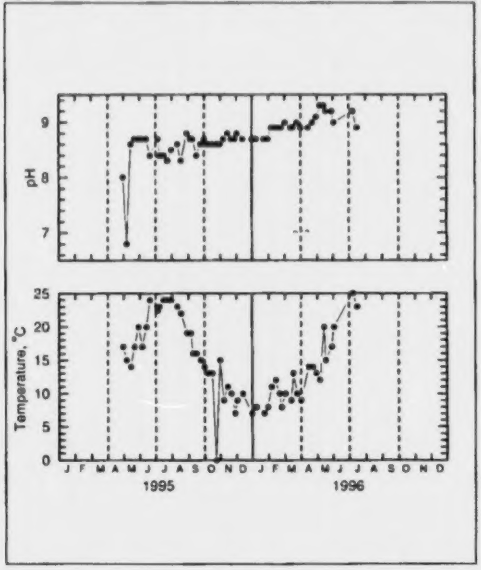
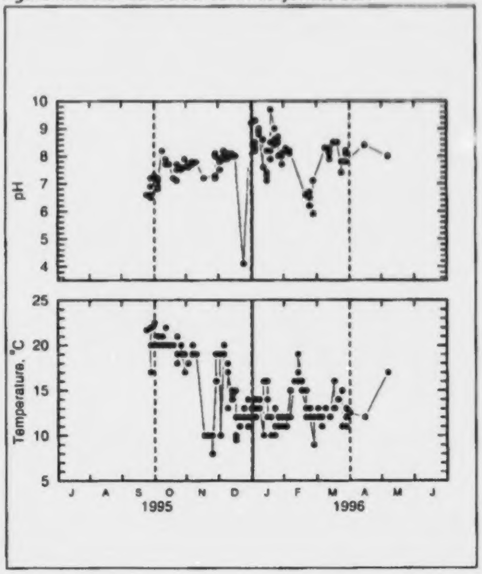


Figure HYD-L-3: GLOBE School in California, USA



The graphing tools can be accessed at the GLOBE visualization location on the GLOBE Student Server. Instructions for accessing the graphing capabilities are available in the Toolkit. Have students try to locate outliers in their own data to minimize the possibility that calibration error or measurement inconsistencies may be influencing data.

You may also use GLOBE visualizations to try to identify daily observations that may be unusual. See Figure HYD-L-6. Students should generate point and contour maps of the weekly observations to try to identify unusual patterns; for example, a light blue point (very low temperature) within an area of orange and red points (warm temperatures). If students find questionable data, they may then locate the data set for that site and try to identify reasons for the anomaly or contact the site using GLOBEMail to ask questions about the data.

Part 2 - Investigating the Range of pH Values

My pH values are jumping around unpredictably.

Figure HYD-L-4: GLOBE School in Florida, USA

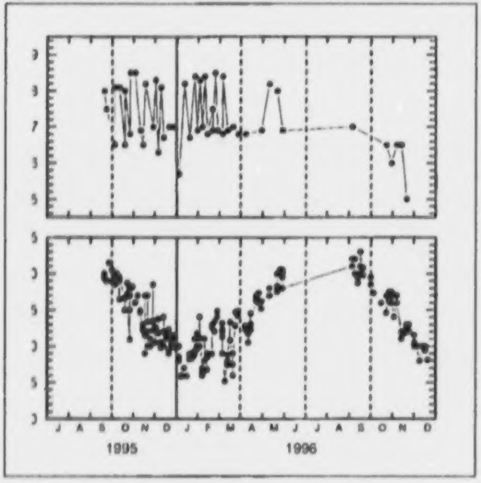
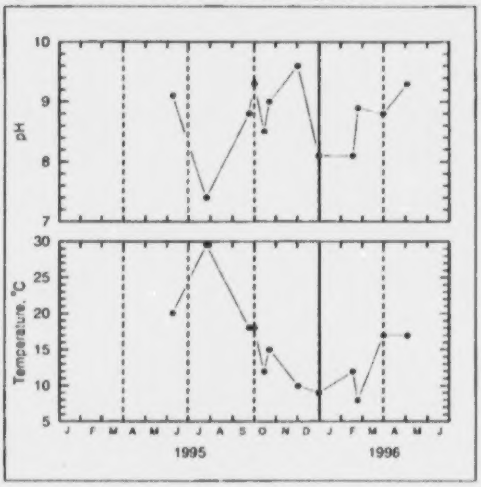


Figure HYD-L-5: GLOBE School in Washington, USA



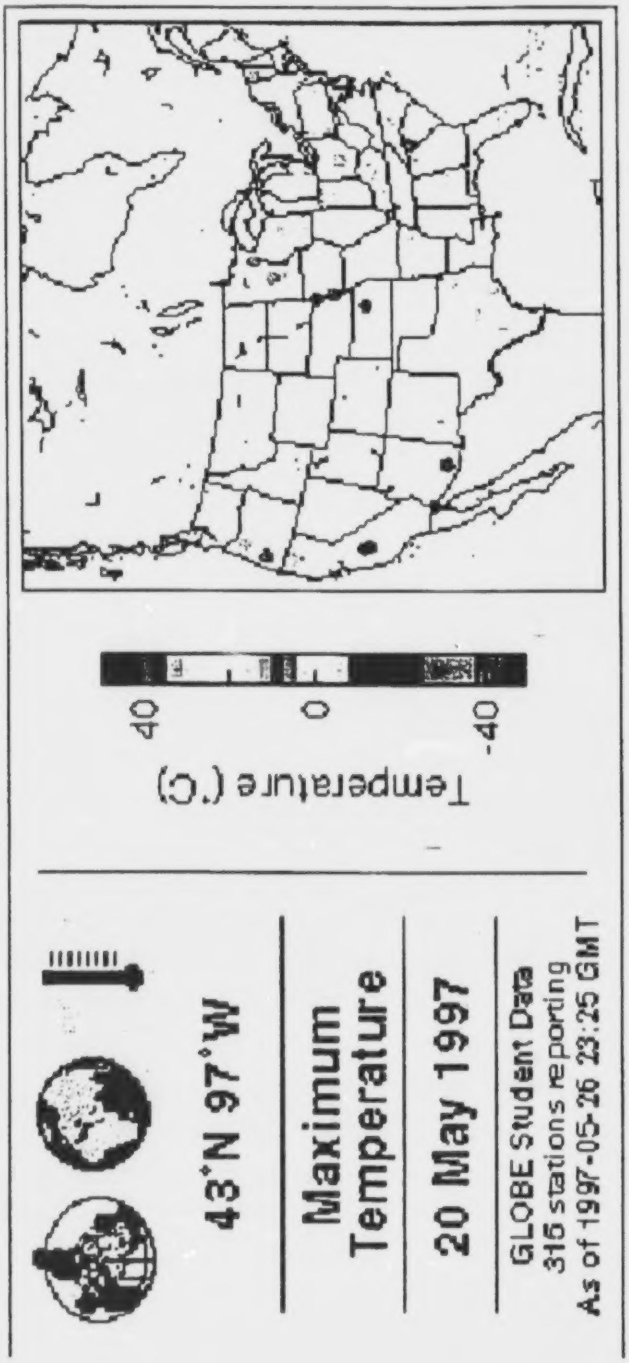
Is this right? Should my pHs be this jumpy?

1. Show students the 2 sets of graphs in Figures HYD-L-4 and HYD-L-5. After they have had an opportunity to examine the graphs and record their observations, ask them to identify any unusual trends.
2. Discuss the range of pH that the students have been finding at their own site. How much variation in pH readings have they found?
3. Have students use the GLOBE graphing tools to graph their own pH data and that of a few other schools. What is the range of their data?
4. Discuss their observations and recommendations.

Note from the scientists

These graphs in Figures HYD-L-4 and HYD-L-5 are good examples of curious pH readings in data sets. Here the pH values seem to be bouncing back and forth over a range of almost 3 pH units. What do you think might be going on in this case? Keep in mind that pH's are usually fairly steady measurements unless there is a major disturbance to a stream or lake such as periodic waste discharge, a very large rainfall, a large algae bloom, or a change in flow rate due to upstream snowmelt. A good example of a periodic change in water flow might also be the discharge from a reservoir upstream. This would significantly affect

Figure HYD-L-6: Temperature from GLOBE Student Data Server

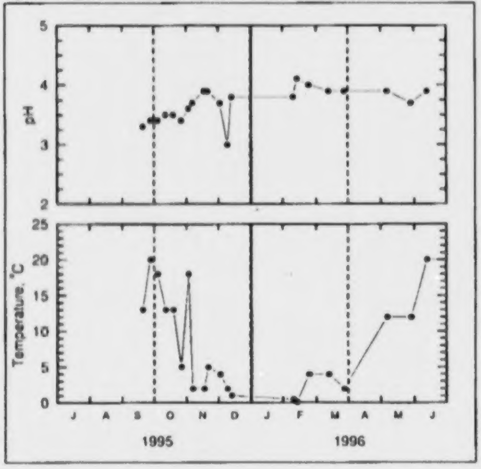

43°N 97°W
Maximum Temperature
20 May 1997
GLOBE Student Data
315 stations reporting
As of 1997-05-26 23:25 GMT
Temperature (°C)
40
0
-40

BEST COPY AVAILABLE

pH values measured downstream. This set of temperature data shows nice, predictable seasonal trends. Are there major disturbances going on, or do these data merely reflect part of the learning process?

I wonder why we're finding such low pH values?

Figure HYD-L-7: GLOBE School in New Jersey, USA



1. Show students the set of graphs in Figure HYD-L-7. After they have had an opportunity to examine the graphs and record their observations, ask them to identify any unusual trends. Would they expect pH readings to be this low? Have them explain why or why not. They should justify their explanation using the data and background information about pH.
2. Ask students to form a hypothesis on why the pH results are so low for this site.
3. Ask them how they could test their hypotheses.
4. Identify other sites from the GLOBE Student Server in the same area. Retrieve the data for these sites and compare them to this site.

Note from the scientists

This graph in Figure HYD-L-7 is an excellent example of a hydrology site exhibiting low pH readings. The question is how likely is it that the pH of the water is really this low? This graph shows a pH data range of about 3 to about 4.5. Natural waters tend to be in the pH range of 6 to 8.

Possibilities

- This is real! If you think this is the case, then the next step is to ask yourselves and your classmates why the pH is so low. What does this say about the path the water has followed to reach this Hydrology Study Site?
- This is a product of how you did your tests. Unfortunately, although we all try our best to make sure our data are accurate, sometimes there is one step we missed which is causing an error in our data. Other times, the materials we have to work with are not in good shape. In the case of low pH values, it seems most likely that the solutions that the school is using for calibration are no longer good. Certainly testing these standards is a good place to start.

Testing your Standard Solutions

To investigate the possibility that your Standard Solutions are not good, you have a couple of choices:

- Buy a new set of standard solutions and compare them to your old ones.
- Calibrate your pH meter with your solutions, then use it to test the pH of a freshly opened soft drink. These products, due to their production standards, are consistently the same pH and can be used as a comparison to see if your pH meters are measuring correctly.

Below is a set of pH's for several soft drinks at room temperature:

Coca-Cola	2.5
RC-cola	2.5
Mr. Pibb	2.8
Pepsi-Cola	2.5
Sprite	3.2

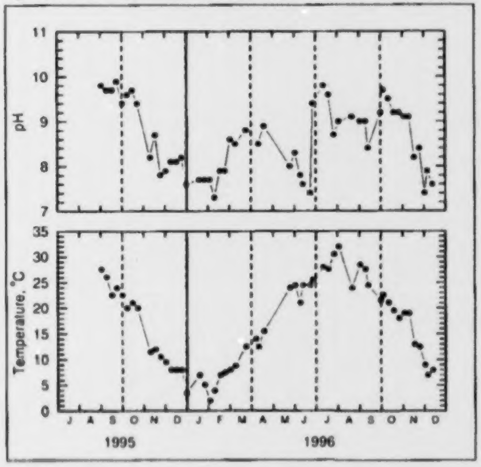
Further Investigations

Have students test their own instruments using the information above.

Part 3 - Identifying pH and Temperature Patterns

This is neat! My pH values and temperatures are going up and down smoothly!

Figure HYD-L-8: GLOBE School in Japan



1. Show students the set of graphs in Figure HYD-L-8. After they have had an opportunity to examine the graphs and record their observations, ask them to identify any unusual trends.
2. Ask students to form a hypothesis on why the temperature graph would show the pattern it does. Does pH normally follow temperature this closely?
3. Graph your own data and data from other sites, especially Japan, using the GLOBE graphing tools, to compare the data with these graphs.

Note from the scientists

Sometimes everything you're doing seems to be right, and you notice what seems to be a really neat trend to your data! As a contributor to the scientific body of knowledge, it is important to look at your data and keep checking to see if you are being accurate. In Figure HYD-L-8 showing data from a GLOBE school in Japan, we see what looks like a consistent and smooth trend in pH. It seems to follow the temperature to a remarkable degree, and even seems to be within a more or less acceptable range.

The data look good! Why the concern?

The data look good because there do not appear to be any major jumps in the measurements, the data are consistently being entered, and the temperature measurements show a smooth and predictable trend. However look at the next couple of observations...

- It is quite unusual for natural processes to change pH by more than 1 or 1.5 units. Also pH values above pH 9.0 are not that common in lakes and streams.
  It would be interesting to see if other schools in the same area show the same trends.
- Although temperature and pH are related to some degree, we would not expect such strong correlation as a result. The pH meters should also be designed to automatically correct for temperature. Was that true in this case?

Part 4 - How will pH Paper and pH Meters Differ?

What was used to take these pH measurements: a pH meter or pH paper?

1. Explain that students in different schools may be using pH paper, pH pens and pH meters to collect pH data.
2. Show students the sets of graphs in Figures HYD-L-9 and HYD-L-10. After they have had an opportunity to examine the graphs and record their observations, ask them to form a hypothesis on what instrumentation was used to take the pH measurements.
3. Ask students how they can justify or support their hypotheses regarding the instrumentation used in collecting the pH data.

Figure HYD-L-9: GLOBE School in the Midwest of the United States

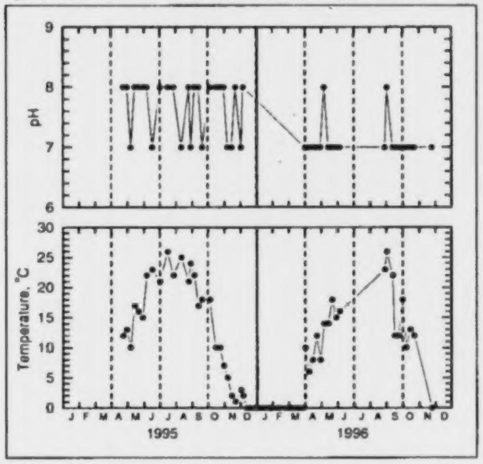
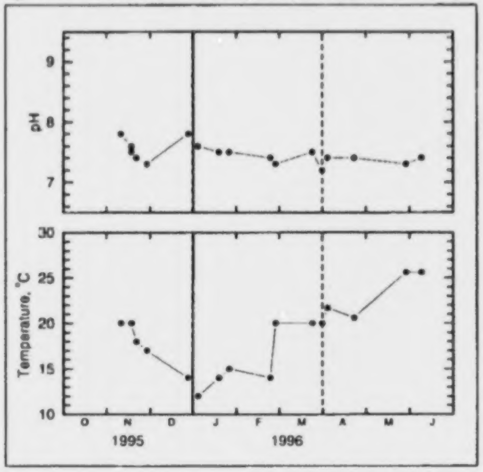


Figure HYD-L-10: GLOBE School in California, USA



Note from the scientists

In the Figure HYD-L-9 we can see that this school is probably making pH measurements using pH paper. This explains the high number of jumps of 1 unit in pH with time. It is entirely possible that the actual pH of the water source being measured by this school in the Midwestern United States is somewhere between pH 7 and pH 8. We would expect slight changes in water pH to push the readings back and forth between two values if they are being made with pH paper.

In Figure HYD-L-10, we see an example of a GLOBE school that is using a pH meter to conduct their measurements. The temperature data show a reasonably smooth temperature progression.

Further Investigations

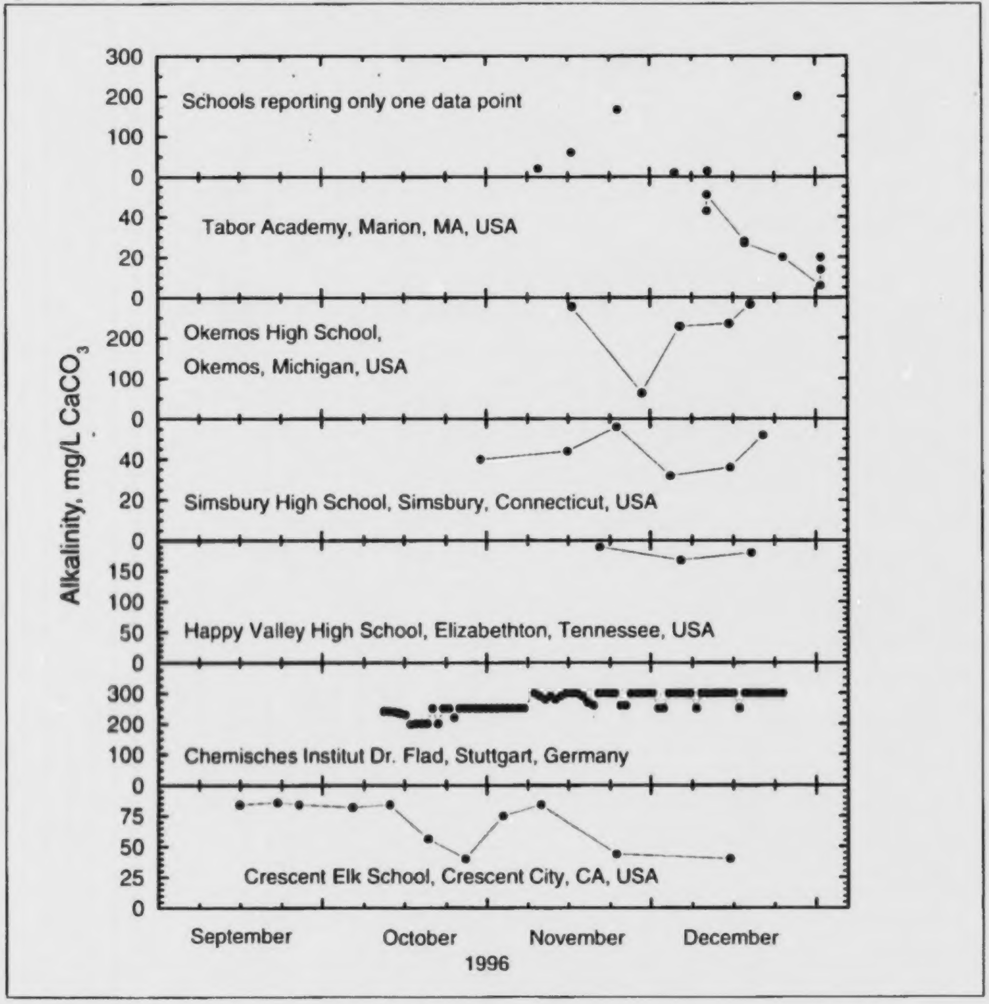
1. Have students recreate the bottom pH graph as if they were using pH paper by taking each point to the nearest whole number and redrawing the graph.
2. Can trends be identified as easily on the old graph as on the new one?

Section 2 - Analysis of New GLOBE Data

Alkalinity was added as a Hydrology protocol in September of 1996. These are a few findings from analysis of some of the earliest schools reporting these data.

1. Have students examine the data from the graphs. How do the data differ?
2. Have students pose questions generated from their observations. For example:
   - What is the data trend? Would you expect it to change seasonally?
   - Do the data seem to be within a normal range?
   - Are there any unusual data points?
3. Have students predict further trends in the data sets.
4. Record the observations, questions, and predictions.
5. Have students devise ways to answer their questions.

Figure HYD-L-11: GLOBE Alkalinity Data, September-December 1996



Note from the scientists

Crescent City, CA, USA is reporting relatively low alkalinity values that exhibit quite a bit of variation with time. These changes could be associated with rainfall, which lowers alkalinity. It will be interesting to put these together with other GLOBE hydrology and atmosphere data for the site in order to gain a more complete picture.

Stuttgart, Germany has a very nice time series that captures even day-to-day changes in alkalinity. They see a slight increase in early November, but otherwise relatively steady values. These relatively high values are from a well-buffered surface water. Again, day-to-day changes could be associated with rainfall.

Elizabethton, TN, USA. Values are intermediate, between those for Crescent Elk School and Chemisches Institut, and are quite consistent with each other. We will be eager to see if alkalinity changes through the winter and into spring.

Simsbury, CT, USA is also reporting relatively low alkalinity values that exhibit some variation with time. In fact, it is surprising that the changes with time are so small, given the range reported. It will be interesting to see if values drop lower during rainfall or snowmelt.

Okemos, MI, USA is reporting alkalinity values that show an interesting drop from nearly 300 mg/L down to about 70 mg/L. We will need to put this together with the other GLOBE hydrology, soil and atmosphere data for the site in order to gain a more-complete picture of what happened.

Marion, MA, USA. Their values are very low and show a steady decline with time. We recommend that they double check their calculations, which if correct show a quite interesting pattern. Are we seeing the effects of tides at this coastal site?

Electrical Conductivity was added as a Hydrology protocol in September of 1996. These are a few findings from analysis of some of the earliest schools reporting these data.

1. Have students examine the data from the graphs. How do the data differ?
    - What is the range of the data within one site?
    - What is the range of data encompassing all sites?
    - What are the data trends? Up? Down? Constant?
2. Have students pose questions generated from their observations.
3. Have students predict further trends in the data sets.
4. Record the observations, questions, and predictions.
5. Have students devise ways to answer their questions by generating hypotheses and justify or support their hypotheses.

Note from the scientists

Belton, TX, USA reports two entries of conductivity measurements from their water site. Both are at very normal levels for a stream system (700 µS/cm, and 745 µS/cm) It will be interesting to see what data show up in the future!

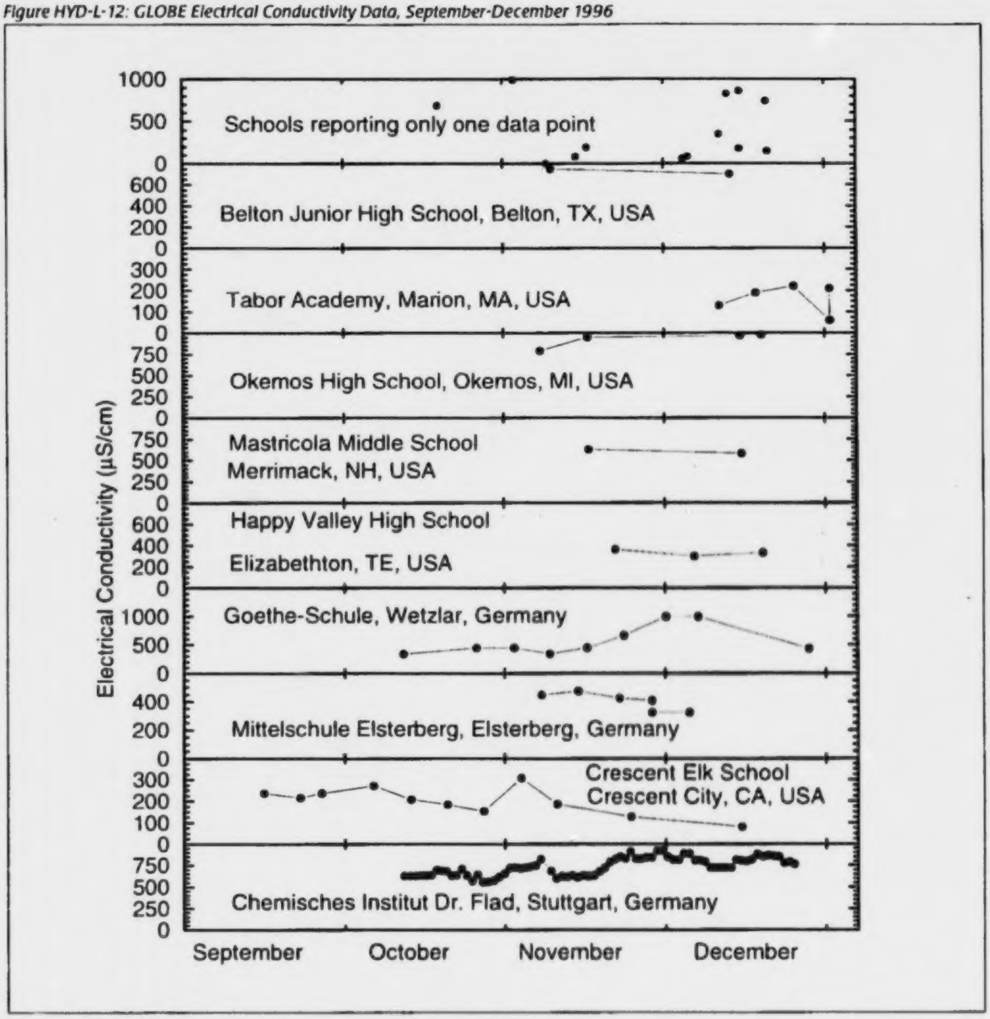
Marion, MA, USA has discovered that their water site consists of relatively pure water with a fairly low conductivity range of 60 µS/cm - 22 µS/cm thus far. Compare these results to what Okemos High School reports and you'll see what a range of impurity levels natural water systems can have!

Okemos, MI, USA measured conductivity with a range of 790 µS/cm - 980 µS/cm! This means that their water is fairly consistently full of dissolved chemicals.

Merrimack, NH, USA has reported 2 conductivity entries, 590 and 630 µS/cm. Look at the other graphs and see where this school falls relatively. What would this indicate about the water? Keep in mind that electrical conductivity is an indicator of what ions are dissolved in the water, and may thus describe the rocks through which the water has flowed.

Elizabethton, TN, USA measures their electrical conductivity in a water source with relatively consistent and low values of conductivity (range: 300 µS/cm - 360 µS/cm) We encourage this school to continue reporting data so we know more about what the water is like in Tennessee and how it changes over the course of the year!

Figure HYD-L-12: GLOBE Electrical Conductivity Data, September-December 1996



Wetzlar, Germany shows the biggest range of measurements of any of the schools we looked at. (Range: 339 µS/cm - 993 µS/cm) They are regularly reporting data every two weeks or so and have found an exciting trend at their site! Over the course of about a month, their conductivity measurements began to climb. What could have caused this change in water chemistry?

Elsterberg, Germany shows that their hydrology water system is fairly consistent in terms of the levels of impurities measured. Their conductivity measurements range from 322 µS/cm to 472 µS/cm. Over the course of their measurements, we see that there has been a slow decline in measured conductivity. What might be causing this?

Crescent City, CA, USA has been reporting data consistently over the 3 month period. Their conductivity measurements appear fairly low. We think we see a gently downsloping trend to the data. Do you? Compare the alkalinity trends and rainfall data to the electrical conductivity trends in Crescent City, USA. Do you see any patterns?

Stuttgart, Germany has developed a real reputation among the hydrology team for reporting many data points. Their conductivity measurements are no exception, and show that their water system changes not only over the course of the three month period of time, but also on a daily basis. Their data range all the way from 552 µS/cm to 920 µS/cm. We think we see evidence for individual storm events in the data here, and possibly a seasonal trend in the levels of impurities. Do you agree? How do these trends compare to rainfall and alkalinity patterns?

Dissolved Oxygen was added as a Hydrology protocol in September of 1996. These are a few findings from analysis of some of the earliest schools reporting these data.

1. Have students examine the data from the graphs in Figure HYD-L-13.
    - How do the data differ?
    - What is the range at different sites?
    - What is the trend in the data?
    - Do all of the data seem to be within normal range? What other information should you consider when judging 'normal range' for dissolved oxygen?
2. Have students pose questions generated from their observations.
3. Have students predict further trends in the data sets.
4. Record the observations, questions, and predictions.
5. Have students devise ways to answer their questions.

Note from the scientists

Belton, TX, USA reported two data points at a level of 9 mg/L. This amount of dissolved oxygen suggests a healthy water source in which fish and plants can live. We encourage Belton to continue making dissolved oxygen measurements, to see how their levels change in the winter and spring.

Marion, MA, USA is measuring a water source where the dissolved oxygen levels are around 10 - 11 mg/L. This range of oxygen levels is supersaturated for a temperature range above 11° C at 0 m. elevation. At the same time that Tabor recorded these DO measurements, they recorded temperatures in a range of 6-8° C. What could cause DO levels to get so high?

Simsbury, CT, USA Simsbury High School reports that their water showed levels of dissolved oxygen at 11 mg/L during October and a sharp rise to a level of 14 mg/L in mid-November. The dissolved oxygen measurements are very consistent until the last entry. We would very much like to know why the last entry is higher. Temperatures measured by Simsbury HS ranged from 1-9° C during this time. On a cautioning note, the recorded temperature when Simsbury HS measured 14 mg/L dissolved oxygen, was 3° C. This DO measurement is supersaturated for this temperature. This suggests that the calibration of Simsbury's dissolved oxygen kit may be off.

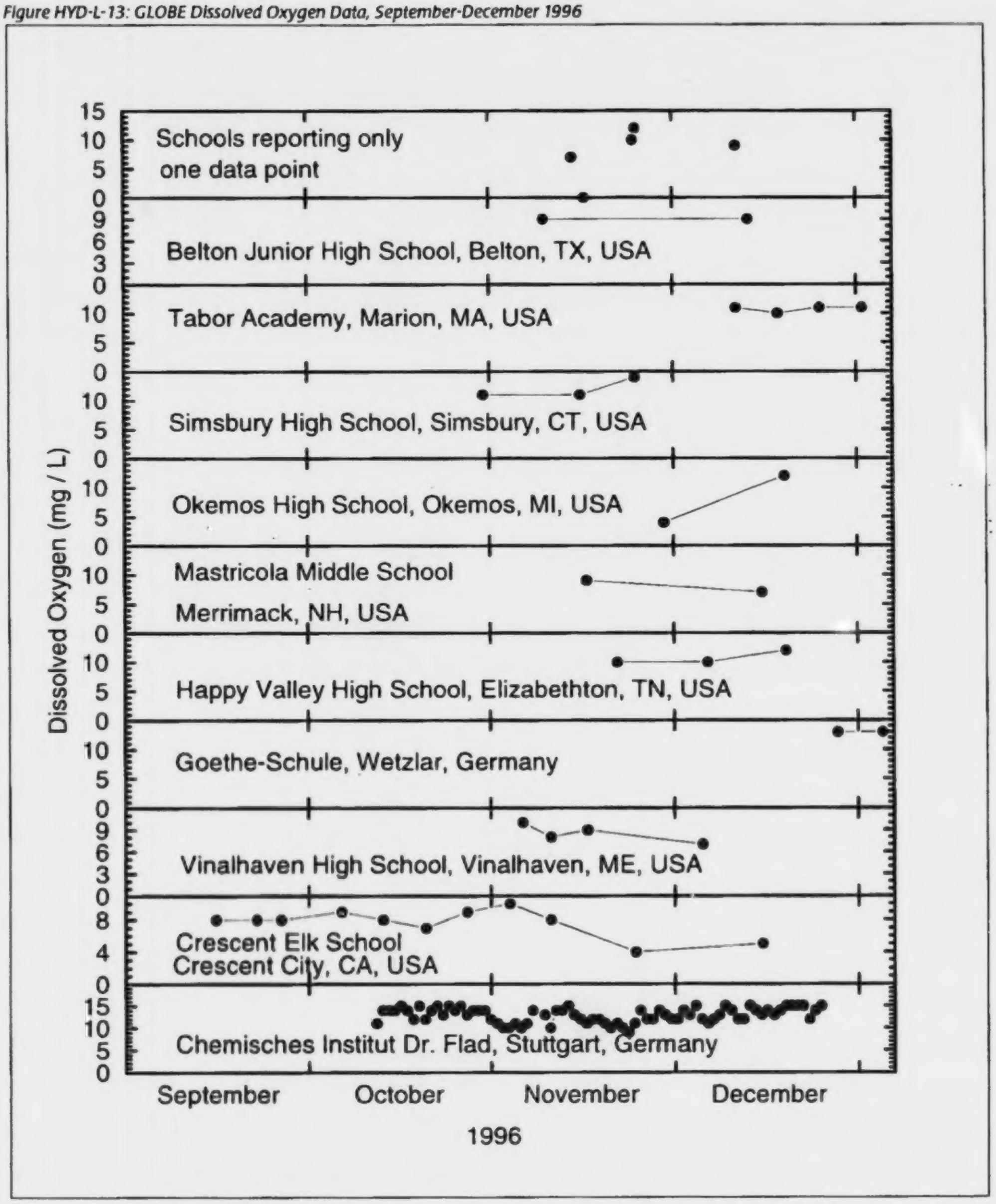
Okemos, MI, USA displays a surprising jump from 4 to 12 mg/L in their DO measurements. Once a careful calibration of equipment used for taking measurements has been done, we propose that if this trend is correct, it might reflect a combination of a drop in water temperature and a drop in the level of biological oxygen demand during the winter.

Merrimack, NH, USA shows a drop in DO from 9 to 7 mg/L over a month period of time, November - December. This drop may represent something interesting in this watershed and we think it is important for the school to think about what may be causing this drop.

Elizabethton, TN, USA measures in their water dissolved oxygen levels that range from 10 to 12 mg/L over a period of about a month. This may be the result of a decrease in water temperature or it may reflect something else. It will be interesting to compare water temperature records with these measurements.

Wetzlar, Germany reports two entries that indicate that their water site possesses fairly high levels of dissolved oxygen (13 mg/L). It is interesting to note that 13 mg/L DO at the temperature recorded, 3.8° C, is very near to saturated. This water source is probably actively mixed with the surrounding air.

Figure HYD-L-13: GLOBE Dissolved Oxygen Data, September-December 1996



Vinalhaven Island, ME, USA initially measured DO levels as high as 10 mg/L but then note a downward trend in their DO over the course of the next month and a half, when they measured it at 7 mg/L. What might cause this kind of drop in oxygen levels? Perhaps certain types of algae that produce oxygen during earlier times of the year begin to die off about this time, and cease to produce oxygen. Another possibility is that the DO level is coming back down from some episode that substantially increased the oxygen level.

Crescent City, CA, USA measures their data on a very regular basis and the data show the changes that take place in their site on a bi-weekly basis. Their oxygen levels gradually go up and down over a range of about 5 to 10 mg/L. It is interesting to note what appears to be an overall decline in dissolved oxygen levels during the 3 month time span shown. This would lead an observer to speculate that the DO levels are decreasing as water temperatures decrease. But does this make sense? Not really, since we would expect DO levels to increase with a decrease in water temperature since cold water can hold more dissolved oxygen than warm water. What might account for this trend? The DO trends follow the conductivity and alkalinity trends. As scientists, we would like to know information about what plant and rainfall activity has occurred over this time period, and about how water discharge levels have changed over this period of time.

Stuttgart, Germany shows the most frequent and consistent series of measurements of the GLOBE schools. They show that dissolved oxygen levels in their area fluctuate over a range of about 10 to 18 mg/L. While trying to figure out what might have produced such high DO measurements, the hydrology team realized that Stuttgart does not always record temperature measurements with their dissolved oxygen entries. Since DO is so temperature dependent, we strongly recommend that schools report water temperature if they measure dissolved oxygen.

Continuing Your Data Analysis

Read the data reports from the Hydrology Investigation on the GLOBE Student Server at the Scientist's Corner. These reports will be updated periodically.

Further Investigations

1. Encourage students to retrieve the current data sets for the schools above and graph the data using the GLOBE graphing tools or import the data into a spreadsheet to graph. What questions were answered by the longer term data set?
2. What questions require other data, such as temperatures or precipitation, to answer. Have students identify data which they think might be relevant and compare it with the Hydrology data. This might include:
   - Does examining soil characterization data help to explain conductivity?
   - What is the relationship between temperature and dissolved oxygen? Are other measurements correlated with temperature?
   - Do dissolved oxygen levels show seasonal fluctuations? What other data fluctuate seasonally?
   - Examine changes in pH at schools with differing levels of alkalinity. Do pH values fluctuate more at sites with high or low levels of alkalinity?
   - Graph precipitation for your site. What hydrology measures changed when you had heavy precipitation? Use the GLOBE contour or point maps to identify other areas showing heavy precipitation for a recent date. What happens to the water chemistry measurements at these sites after the rain?

Were further questions generated by the longer term of data collection? Record these questions and encourage students to come up with methodologies for further research.

Suggestions: Use the GLOBE maps to identify sites with similar latitudes for comparison. Identify 'control sites', or sites which are similar to the one you are investigating except for the variable you are interested in. For instance:

1. Use GLOBEMail to ask questions about site information not reported to the GLOBE data server and to share research with other schools.
2. Use the graphing capabilities of the GLOBE graphing tools to graph data from 2 schools for comparison
3. Use topographic maps to identify watersheds. Zoom into the region you identify in the GLOBE visualizations and find GLOBE sites contained in that watershed. Graph water chemistry data from sites within the watershed to try to identify changes along the course of the waterway.

As more data are added to the GLOBE Student Data Server, continue to identify schools which are of interest to you. Find schools in locations similar to your own. Are their hydrology data similar to yours?

Ask students to critically examine their own data using maps and graphs to look for patterns or unusual data. Ask questions, identify ways to explore their data for answers, and begin to explore their own site.

Student Assessment

Students should be able to identify trends, anomalies and problems with data sets. This capability can be demonstrated in class discussions and by providing them with examples of graphs and asking them to explain the trends, anomalies and issues which they come up with by analyzing the data as a written exercise. They should also be able to demonstrate an understanding of the limitation of what can be understood from a data set. They should be able to use the GLOBE graphing tools to create graphs and analyze data that they find and prepare. Through this activity the students should also gain an understanding of the GLOBE measurement parameters such as pH, temperature and alkalinity. The science content understanding can be assessed in the context of the assessment of the student's understanding of the science of data sets.

Macroinvertebrate Discovery

Purpose

To determine the diversity of benthic (bottom dwelling) macroinvertebrates at your Hydrology Study Site and to investigate the correlations between macroinvertebrates and water chemistry measurements.

Overview

Students will establish a diversity index for benthic macroinvertebrates by sorting and counting organisms collected from the site, and in the process become familiar with many taxa of macroinvertebrates. They will then investigate the relationship between the taxa they found and their water chemistry measurements.

Time

One class period to do the practice exercise

One class period to collect sample and one class period to do the counts and calculate the index

Level

All

Key Concepts

- Species diversity is related to water chemistry
- Species have different habitat requirements
- Random sampling can be used to determine species diversity

Skills

- *Calculating* a diversity index
- *Performing* a random sample
- *Building* tools
- *Identifying* taxa
- *Discovering* species habitat parameters
- *Taking* water chemistry measurements

Materials and Tools

For Practice Activity

- Shallow, white tray or pan (such as a styrofoam meat tray) - about 60 X 40 cm
- Black marker
- Ruler
- Small candies, cake decoration confetti, or other items of varying colors or shapes to sample
- Macroinvertebrate Work Sheet
- Ice cube tray for sorting taxa
- Small pieces of paper numbered from 1-50 for drawing random numbers

For Field Activity

- Sorting and sampling kit (3 sets needed)
    - Shallow white pan for sorting, about 30 x 20 cm
    - Shallow white tray for counting, about 60 x 40 cm
    - Black permanent marker
    - Ice cube tray for sorting taxa
    - 10-20 mL bulb basting syringe (end should be approximately 5 mm diameter)
    - Large plastic forceps
- Magnifying glass
- 3 mL Pasteur pipette (eye dropper) (end should be approximately 2 mm diameter)
- 4-L sample container with lid (or 4 1-L containers)
- Set of numbered tiles or paper
- Bucket for pouring water through net
- Additional containers with lids if macroinvertebrates are to be brought back to the classroom
- Macroinvertebrate Work Sheet

And either:

kick screen (for running water, rocky bottom sites)

91 x 122 cm nylon screen(2 mm mesh size)

2 poles (122 cm long, 1-2 cm dia)

staples

2 pieces of denim or other heavy fabric (8 x 122 cm each)

needle and thread or heavy waterproof tape

or

D-net (for muddy bottom, still water)

2 pieces of nylon window screen (36 x 53 cm)

3 wire coat hangers

Heavy denim or fabric (8 x 91 cm)

Needle and thread or heavy waterproof tape

152 cm pole (e.g. broom or rake handle)

4 cm pipe clamp

Preparation

Make or buy appropriate net.

Copy Macroinvertebrate Work Sheets.

Collect materials for Sampling Kits.

Collect pictures or books illustrating local macroinvertebrates.

Prerequisites

Students should begin collecting GLOBE water chemistry data.

Background

Benthic macroinvertebrates are small, spineless animals that can be seen without a microscope, generally larger than one mm, which live in the mud or gravel in the bottom of water bodies. These include many larva of insects such as mosquitoes, dragonflies and caddisflies which begin their lives in the water then become land-dwelling insects when they mature. Other examples of common benthic macroinvertebrates include crustaceans such as crayfish, snails, and worms and leeches. These creatures populate the mud or gravel at the bottom of ponds or streams in amazing numbers - often thousands in a square meter. They are often an important part of the food chain.

Macroinvertebrates can tell us a lot about the conditions within a water body. Many macroinvertebrates are sensitive to changes in pH, dissolved oxygen, temperature, salinity, and other habitat parameters. A particular organism requires a consistent water quality to live its full life span.

For the *Macroinvertebrate Discovery* activity we want to establish a diversity index for your hydrology site. Biological diversity is a measure of the number of different kinds of organisms in an ecosystem. It is not a measure of the total number of organisms in the system. For example, you might have an equal number of organisms in a stream with low pH as in a stream with a more neutral pH. But because some types (taxa) of macroinvertebrates would not survive in the low pH stream, the diversity, or total number of different taxa, would be less. You might simply have a larger number of the organisms within each of the taxa which were tolerant of low pH.

What to Do and How to Do It

There are a number of good resources for identifying and researching macroinvertebrates. You will find some of these listed at the end of this activity.

1. Have students investigate the conditions under which different macroinvertebrates live. They may use their own observations, outside references, or the tables at the end of this investigation.
2. Have students form hypotheses on what macroinvertebrates they may find at their water site during the current season. Have them record their research, hypotheses and justification in their GLOBE Science Notebooks. They may want to sketch some of the common macroinvertebrates in their notebooks with notes on identification for field reference.

Calculating the Diversity of Macroinvertebrates in the Field

Preparation

Gather materials for sampling and doing the diversity index. If necessary, make a sampling net using the instructions given at the end of this activity. **Note:** There are two methods to collect your macroinvertebrate sample, depending upon your water site. If you have a rocky/gravel substrate with a current then you should use a Kick Screen. If you have a site with a muddy bottom with virtually no current then you should use a D-Frame net.

Students should do the Practicing the Diversity Index Activity at the end of this activity before they go into the field. This will give them practice in going through the exercise and help them to understand the concept of random sampling.

Collecting Y our Sample

Collect the water chemistry measurements for your site. **Note:** Be sure the water is safe to enter and follow appropriate safety procedures with the students in the water.

Using a kick screen to collect sample:

1. Divide class into groups of 3-4 students and give each group a pail, net, and sampling kit.
2. Have each group identify a sample site. Sites should be within a few meters of each other, but represent different regions of the stream; for example a weedy area and a rocky area.
3. Beginning with the group farthest downstream, have one or two people from each group use either their feet and hands or a stick to disturb the bottom material, while 2 people hold the net 1-2 m downstream from the disturbance. The kicking or stirring should last for at least a minute. Also overturn and scrape the undersides of rocks. For safety reasons, if the area of collection is deeper than one-half meter, do not stand in the water.
4. Lift the net from the water by moving the bottom of the net forward along the bottom of the stream in a scooping motion so that nothing escapes from the net. Using 100-200 mL of water from the site, rinse material from the net into the sorting pan.
5. Have two people from each group pick out organisms using basting syringe or forceps and put them into containers filled with sample water.
6. Repeat steps 3-5 for each student group in order to collect a representative sample. **Note:** If sample area is shallow enough, try to get samples from all the way across the area.

Using a D-frame net to collect sample:

1. Divide class into groups of 3-4 students and give each group a pail, net, and sampling kit.
2. Have each group identify a sample site. Sites should be within a few meters of each other, but represent different regions of the stream; for example a weedy area and a rocky area.
3. Have the first group put the net into the water until it reaches the bottom substrate. Use the net to disturb the substrate for about 30 cm. Glide the net across the bottom of the disturbed area for about 30 cm and then bring it back up to the surface.
4. Pull the net out of the water so that nothing falls out. Using 100-200 mL or water from the site, rinse material from the net into the sorting pan.
5. Have two people from each group pick out organisms using basting syringe or forceps and put them into containers filled with sample water.
6. Repeat steps 3-5 for each student group in order to collect a representative sample. **Note**: If sample area is shallow enough, try to get samples from all the way across the area.

Calculating the Diversity Index:

1. Draw a grid on your counting tray of 4 cm squares.
2. Number the squares consecutively.
3. Pour your sample onto the tray more or less equally distributed across the grid in about 1 mm of water.
4. Have one student draw a number.
5. Have another student find that number on the grid and remove one organism using the Pasteur pipette or forceps. Place this organism (organism 1) in a bowl with water. Note: if there is nothing in the square drawn, draw another number.
6. Put an X on your Work Sheet to represent organism 1.
7. Pick organism 2 from the same square, or if there is nothing else in that square draw another number and sample from the new square.
8. Place organism 2 next to organism 1 in the bowl.
9. If organism 2 is the same as organism 1, put an X on the Work Sheet. If organism 2 is different from organism 1, put an O on the Work Sheet.
10. Put organism 1 into one compartment of the ice cube tray or taxa bowls.
11. Pick organism 3 from the same square, or draw a new square if needed.
12. Place organism 3 next to organism 2.
13. If organism 3 is the same as organism 2, put down the same mark on the Work Sheet as you used for organism 2 (X or O). If organism 3 is different from organism 2, put the opposite mark.
14. Place organism 2 into the ice cube tray. If it is the same as organism 1, put it with organism 1. If it is different, put it into a new compartment.
15. Continue to draw random numbers and take samples, recording each sample as X or O, then sorting the taxa into compartments until 50 samples are taken.
16. Count the number of 'runs' on your Work Sheet (see example below) and record.
17. Divide the number of runs by the number of organisms counted (50) and record the number on your Work Sheet.
18. Count the number of different taxa in your sample and record.
19. Multiply the two numbers, and record. This is the diversity index.
20. Have students try and identify as many taxa as possible.

Work Sheet Example:

X X O O O X O O X

1—2——3 4—5

In this particular example, there are 5 runs

Further Investigations

1. Students should identify as many macroinvertebrates as possible from their sample.
2. Compare their hypotheses with the actual taxa they identified.
3. Formulate hypotheses on what conditions may cause certain taxa to exist unexpectedly, or why some common taxa may be missing.
4. Use the GLOBE data server to find schools with a hydrology study site similar to your own. Begin by searching for schools within your watershed or at the same latitude and elevation with similar pH, temperature, dissolved oxygen and salinity levels.
5. Use GLOBEMail to contact these schools and ask about the macroinvertebrates they are finding.

Habitat Parameters for Selected Macroinvertebrates

*pH Range for Selected Macroinvertebrates**

TAXA	1	2	3	4	5	6	7	8	9	10	11	12	13	14
mayfly						XXXX								
stonefly						XXXX								
caddisfly						XXXX								
snails							XXXXXXXXX							
clams							XXXXXXXXX							
mussels							XXXXXXXXX							

* pH ranges 1-6 and 10-14 are unsuitable for most organisms

Temperature Range for Selected Macroinvertebrates

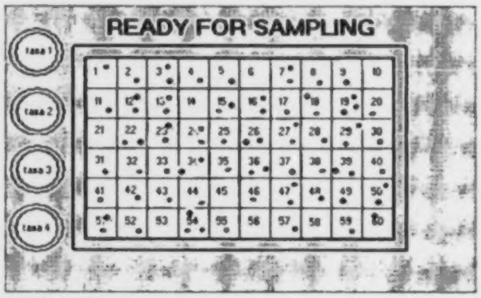
TAXA	Cold Range < 12.8° C	Middle Range 12.8-20° C	Warm Range > 20° C
caddisfly	x	x	x
stonefly	x	x	
mayfly	x	x	
water pennies	x		
water beetles		x	
water striders		x	
dragonfly		x	x

Minimum Dissolved Oxygen Levels for Selected Macroinvertebrates

TAXA	High Range 8 - 10 ppm	Medium Range 4 - 8 ppm	Low Range 0 - 4 ppm
stonefly	X		
water penny	X		
caddisfly	X	X	
some mayflies	X	X	
dragonfly		X	
true bugs		X	
damselfly		X	
mosquito			X
midge			X
tubiflex worm			X
pouch/lung snails			X
rat-tailed maggot			X

Practicing the Diversity Index Activity

1. Draw a grid on your tray of 4 cm squares.
2. Number the squares consecutively.
3. Scatter your sample onto the tray more or less equally distributed across the grid.
4. Have one student draw a number.
5. Have another student find that number on the grid and remove one piece. Place this piece (Sample 1) on the table. If there is nothing in the square, draw another number.
6. Put an X on your Work Sheet to represent Sample 1.
7. Pick Sample 2 from the same square, or if there is nothing else in that square draw another number and sample from the new square.
8. Place Sample 2 next to Sample 1 on the table.
9. If Sample 2 is the same as Sample 1, put an X on the Work Sheet. If Sample 2 is different from Sample 1, put an 0 on the Work Sheet.
10. Put Sample 1 into one of the taxa bowls or cube compartments.
11. Pick Sample 3 from the same square, or draw a new square if needed.
12. Place Sample 3 next to Sample 2.
13. If Sample 3 is the same as Sample 2, put down the same mark on the Work Sheet as you used for Sample 2 (X or 0). If Sample 3 is different from Sample 2, put the opposite mark.
14. Place Sample 2 into a taxa bowl. If it is the same as Sample 1, put it with Sample 1. If it is different, put it into a new taxa bowl.
15. Continue to draw random numbers and take samples, recording each sample as X or 0, then sorting the taxa into bowls until 50 samples are taken.
16. Count the number of 'runs' on your Work Sheet. (See example below.)
17. Divide the number of runs by 50 (your sample number).
18. Multiply this number by the number of different taxa. This is your diversity index.



Further Practice

Have students calculate a Diversity Index using fewer number of taxa or a different distribution of numbers within the taxa. Compare the results.

Work Sheet Example

Record— XX 0 0 0 X 0 0 X

Sample # 1 2 3 4 5 6 7 8 9
Run 1—2——3 4—5

The example above shows that Sample 1 and 2 were alike. Sample 3 was different from 2. Samples 4 and 5 were like Sample 3. Sample 6 was different from Sample 5, etc. There are 5 runs.

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Resources for Research on Freshwater Benthic Macroinvertebrates:

Caduto, M.J. (1990).*Pond and Brook: A Guide to Nature Study in Freshwater Environments.* 2nd ed. Prentice-Hall, NJ.

Cromwell, Mare et al. (1992) *Investigating Streams and Rivers.* GREEN, University of Michigan, Ann Arbor.

Maitland, Peter S. (1990). *Biology of Fresh Waters.* Blackie, Glasgow and London.

Merrit, R.E. and K.W. Cummins (1988). *An Introduction to the Aquatic Insects of North America.* Kendall-Hunt Publishing Co., Dubuque, Iowa.

Mitchell, Mark K. and Stapp, William B. (1996). *Field Manual for Water Quality Monitering,* Ann Arbor, Michigan 48104.

McCafferty, P.W. (1981). *Aquaticentomology: The Fishermen's and Ecologist's Guide to Insects and Their Relatives.* Jones and Barlett Publishers, Inc. California.

Needham, James G (1962). *A Guide to the Study of Fresh-Water Biology.* Holden-Day, Inc. San Francisco.

Pennok, Robert. (1973). *Freshwater Invertebrates of the United States.* Ronald Press, NY.

River Watch Network, 153 State St., Montpelier, Vermont 05602.

Save Our Streams, The Izaak Walton League of America, 1800 North Kent Street, Suite 806, Arlington, Virginia 22209.

Video (17 min): *Identification of the Benthic Macroinvertebrates;* Edward A Deschuytner, Northern Essex Community College, Elliott Way, Haverhill, MA 01830-2399.

Instructions for Making Macroinvertebrate Nets

Making the Kick Screen

1. Fold one 8 x 122 cm strip of fabric over one of the long screen edges and sew, reinforcing the edge.
2. Repeat for the other long edge.
3. Attach screen to poles with staples, making the poles even with the bottom of the screen and extending to form handles at the top.
4. Wrap screen around poles several times and staple again to reinforce the edges.

Making the D Net

1. Cut a net shape from the two 36 x 53 cm pieces of nylon screen (see diagrams) and sew them together.
2. Edge the open end of the net with heavy fabric, leaving an opening to form a casing to insert the hanger.
3. Cut hooks from hangers and untwist the wires.
4. Use duct tape to tape the hangers together to make your frame heavier.
5. Insert a wire through the casing and twist ends back together at opening.
6. Drill a hole in the tip of the wooden handle large enough to insert the ends of the hangers. Insert the ends of the hangers into the hole in the pole. Secure the net to the pole by using the hook you cut from the hanger and using the pipe clamp or duct tape to secure the hook to the pole.

Figure HYD-L-14: Making the Kick Screen

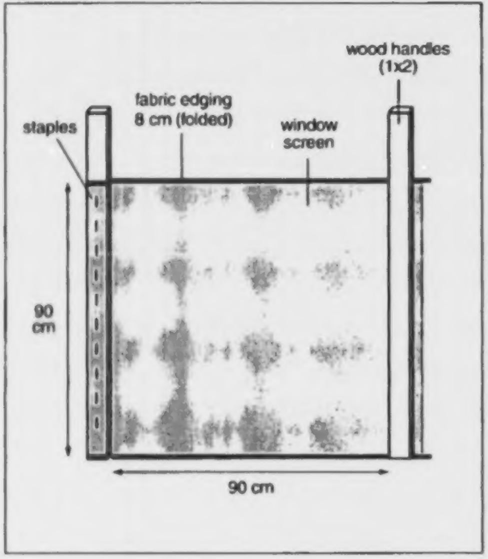
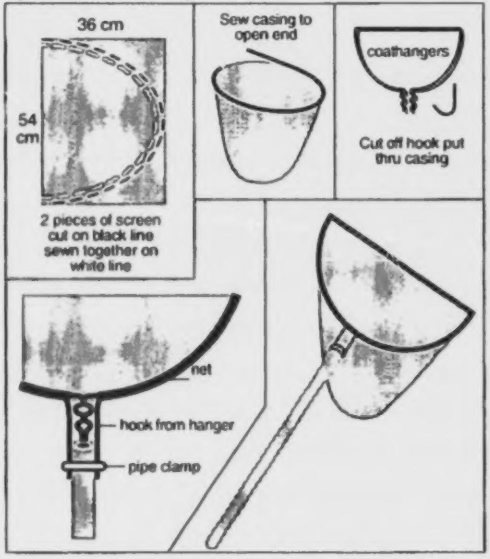

wood handles (1x2)
fabric edging 8 cm (folded)
staples
window screen
90 cm
90 cm

Figure HYD-L-15: Making the D Net


36 cm
54 cm
2 pieces of screen cut on black line sewn together on white line
Sew casing to open end
coathangers
Cut off hook put thru casing
net
hook from hanger
pipe clamp

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Hydrology Investigation

Macroinvertebrate Activity Work Sheet

Station name: ____

GPS coordinates: Latitude: __________________ Longitude: __________________

Collector's name(s): ____

Sample Collection: Sample #: ________ Date: ______________ Time (UT): ______________

Analyst's name(s): ____

Analysis (calculation of diversity index): Date: ______________ Time (UT): ______________

Collecting Method: ________ D net ________ Kick Screen

Calculation of # of runs:

Grid Number

X or 0

Grid Number

X or 0

Total # of Runs ________

Total # of Runs / # Sampled (50) = ________ (Run Index)

Total # of taxa: ________

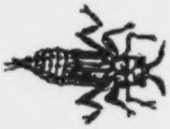
(Run Index) x (Total # of Taxa) = ________ (Diversity Index)

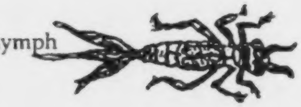
Check Type of Macroinvertebrates Found, if known

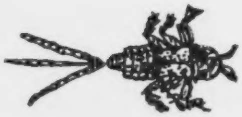
Caddisfly (Trichoptera)	Stonefly (Plecoptera)
Mayfly (Ephemeroptera)	True Bugs (Hemiptera)
Worms & Leaches	Snails
Dragonfly/Damselfly (Odonata)	Dobsonfly, Fishfly, Alderfly (Megaloptera)
Beetles (Coleoptera)	Blackfly, Midge, Crane fly, Mosquito (Diptera)
Mites (Arachnids)	Crustaceans (e.g. Sowbug, Scud)

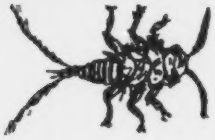
Notes: (water depth, recent rain, rocky, weedy, etc.)

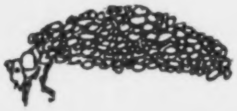
Examples of Macroinvertebrates

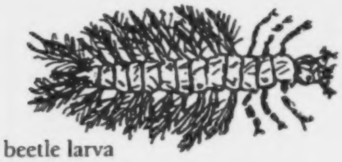

1. dragonfly nymph

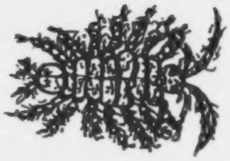

2. damselfly nymph

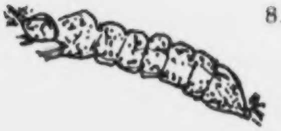

3. mayfly nymph

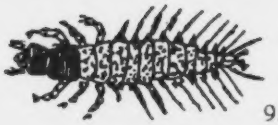

4. stonefly nymph

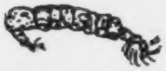

5. caddisfly larva

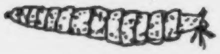

6. whirligig beetle larva

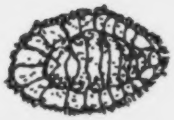

7. aquatic sowbug

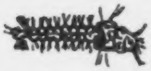

8. blackfly larva

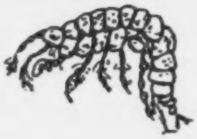

9. dobsonfly larva


10. midge larvae


11. crane fly larvae


12. water penny beetle larva


13. mosquito


14. scud

Modeling Your Water Balance

Purpose

Use GLOBE temperature, latitude, and precipitation data to model the change in soil water storage over a year's time, then to compare your model with GLOBE soil water content and biometry data.

Overview

Students will create a physical model using glasses to represent the soil column that illustrates the soil water balance. They will use data from the GLOBE Data Server to calculate the potential evapotranspiration (the amount of water needed to meet the demand for the month), average monthly temperatures and precipitation for their model. They will then construct a model representing the soil water balance for their site.

Time

One class period to calculate values

One class period to construct model

One class period for hypothesis testing

Level

Intermediate and advanced

Key Concepts

- Soil stores water.
- Soil has a water holding capacity (field capacity).
- Higher temperatures and longer periods of daylight increase evapotranspiration.
- Precipitation is not equal to the amount of water stored in the soil.
- Soil water content is related to vegetative growth.

Skills

- *Measuring* volume and length
- *Following* directions
- *Building* models
- *Retrieving* data from the GLOBE server
- *Reading* graphs
- *Calculating* averages
- *Testing* hypotheses using models
- *Graphing* GLOBE data

Materials and Tools

- 14 beakers, glasses, or graduated cylinders (approximately 20-25 cm tall, or tall enough to hold the total precipitation for the wettest month at your model site)
- Water (or other medium to represent precipitation such as rice)
- Red and black markers
- Ruler
- Data from example or from GLOBE server

Preparation

For advanced activity: Collect GLOBE temperature, precipitation, GPS, soil moisture, biomass and hydrology data

Prerequisites

Simple math calculations, reading graphs, using GLOBE Data Server

Background

The amount of water stored in the soil at your site can be estimated by conducting a water balance for your area. The water content of your soil varies depending on the balance between water gained due to precipitation and water lost through evaporation and transpiration. The combined amounts of water lost through evaporation and transpiration is called evapotranspiration. The maximum rate of evapotranspiration would occur if water was always available and is called potential evapotranspiration. The water content of your soil is a key factor in determining which plants can grow in your area. Several factors control the water content of your soil including temperature, the duration of sunshine, the amount of groundcover and the amount of precipitation. One might think that the months of highest precipitation would also be the months with the greatest soil water content. This may be true- but maybe not - if the temperatures are so great that most of the water evaporates! Scientists study the water balance in an area to predict when plants will grow and when they will be under stress due to lack of water.

Preparation

Discuss with students the importance of water held in the soil with your student. You may want to do the *Just Passing Through* activity to illustrate the holding capacity of different soils.

Copy the Work Sheets for students to use.

What to Do and How to Do It

Examine the data in Figure HYD-L-16.

Precipitation = total amount of precipitation for the month

Water Needed (PE) = Potential Evapotranspiration is the total amount of water that would be lost through evaporation and transpiration if water was always available.

Extra Water = Precipitation in excess of what is needed

Extra Water Needed = Water needed from storage to make up a shortage in precipitation

Water in Storage = Water stored in soil available for plants (cannot exceed 100 mm, because this is the field capacity for this site)

Water Shortage = Water that is needed in excess of precipitation and ground storage

Runoff = Water which is lost through runoff when precipitation is greater than need and ground storage is at capacity

Temperature = average monthly temperature

Figure HYD-L-16: Water Balance Table, Mt. Lemmon, AZ Practice Data

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Precipitation (mm)	69	23	98	56	9	23	183	71	23	32	68	54	
Water Needed (PE in mm)	13	7	16	33	64	99	101	96	86	60	27	7	
Extra Water													
Extra Water Needed													
Water in Storage													
Water Shortage													
Runoff													
Temperature (avg in Celsius)	2	2	4	8	12	17	18	17	16	12	7	3	

1. Which month has the most precipitation? Which has the least?
2. Which month is the warmest? Which is the coldest?
3. During which months will water needed (PE) exceed precipitation?
4. During which months might you expect to have runoff?
5. Make a hypothesis on which month or months you would expect to have a water shortage. Record your hypothesis and your justification for your hypothesis in you GLOBE Science Notebook.

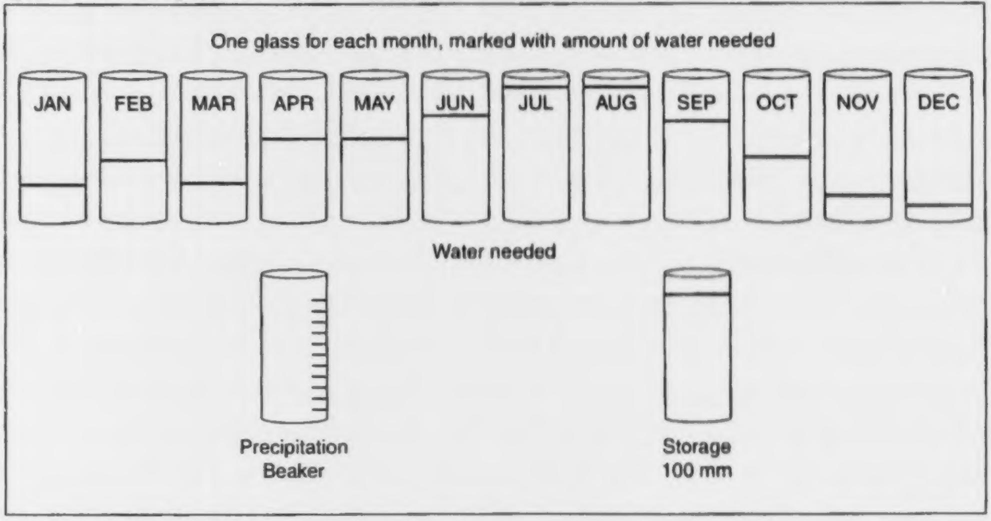
Setting Up Your Model

1. Set out 12 containers representing months of the year. Label them from January through December. See Figure HYD-L-17.
2. Find, in the table, the amount of potential evapotranspiration (PE) that is needed for each month. Draw a line on each container with a marker showing the mm of PE needed for that month.
3. Mark the 13th container as storage. Make a line at 100 mm on the container to indicate when storage is full.

Using Your Model

1. Begin modeling your water balance by measuring in the precipitation beaker the amount of precipitation you received for January. Then follow the procedure below:
   - If you have more precipitation than you need for the month, fill the month container only up to the PE line, then put the extra water from the precipitation beaker into storage.
   - The Storage container can only be filled to the 100 mm level; extra water is runoff and can be thrown away.
   - If you do not have enough precipitation for the month to fill to the PE line, pour all of the precipitation into the month container, then take water from storage and pour it into the month container until you reach the PE line.
   - If you still do not have enough water after pouring in all of the precipitation from the beaker and using all of the storage, make a red line on the glass at the water level to show a water shortage.
2. As you create the water balance model, fill in the Water Balance Table Work Sheet with the appropriate data for each month. (Review the example of the filled in Water Balance Table on the Water Balance Table Work Sheet.)

Figure HYD-L-17: Setting Up for the Water Balance Model



3. Repeat these steps for all of the months. Do the months in order so that you will know how much is in storage each month.

Notes

1. Sand, rice or some other material can be used instead of water.
2. Try starting the experiment with January, then start with October. In the U.S. and some other areas, hydrologists define a "water year" as starting in October, before the winter snow accumulation season. Do you get a different result?

Discuss Your Results:

1. Which months show a water shortage? Did this agree with your hypothesis? Are there any variables which you might now take into consideration in forming a hypothesis on water shortages at a site?
2. Are water shortages always in months with the least precipitation?
3. Are water shortages always in months with the highest temperatures?
4. During which months might you expect floods? Justify your hypothesis.

Testing Other Hypotheses With Your Model

Form hypotheses predicting how the water balance will change with changes in the variables

1. What happens if you have a particularly wet winter? (increase the winter precipitation)
2. What happens if you have an unusually dry summer? (decrease the summer precipitation)
3. What happens if you have an unusually hot summer (increase the water needed (PE) for the summer months)
4. What happens if you increase your storage through building an artificial reservoir? (increase Storage to 150 mm)

Test your hypotheses by changing the variables in the table and running the model again.

Adaptation for Older Students

Have students complete the Water Balance Table Work Sheet for their own or another site using GLOBE data.

1. Find the average monthly precipitation for each month and fill in the precipitation row in the table.
2. Find the average monthly temperature for each month and fill in the temperature row in the table.
3. Find the latitude for your site and fill in the latitude.
4. Find the PE for each month and fill in the PE row in the table. (PE may be calculated using the Calculating the PE Work Sheet in the appendix)
5. Find the difference between the precipitation and the water needed (PE) for the month.

- If there is more water than needed, enter the difference in the extra water row.
- Also enter this difference into the water storage row, adding it to any water that is already in Storage from the previous month. **Note:** In the first month you do not have a number to add from the previous month, so just enter the difference.
- Storage cannot be <0 or >100. Put the amount over 100 mm into runoff.
- If there is less water than needed, enter the difference into the extra water needed row.
- Subtract (water in storage from the previous month) - (extra water needed from the current month).
- Enter this number into the current month water storage box if it is >0.
- If the number is <0, enter 0 in the water storage box and your answer into the water shortage box.

6. Students should also calculate the actual amount of water loss through evapotranspiration:

   If Precipitation > PE:

   Actual Evapotranspiration = PE

   If precipitation < PE (as long as there is water in storage):

   Actual Evapotranspiration =

   Precipitation + extra water needed

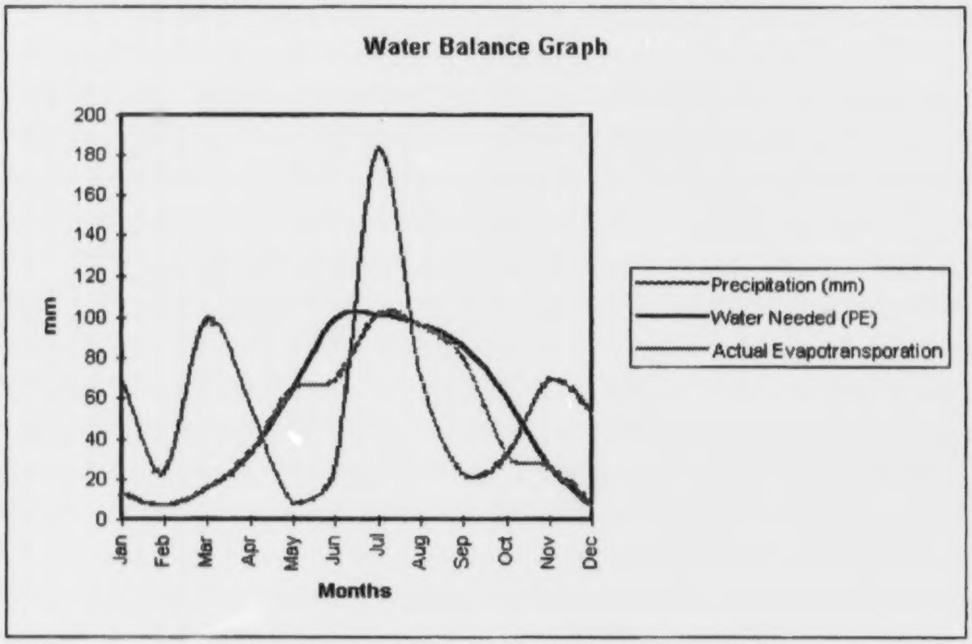
   You can only add the amount of water that is available in storage.

Graph the precipitation, actual evapotranspiration, and PE (3 lines) for the site on one graph using the months on the X axis, and mm of water on the Y axis for Precipitation, Actual Precipitation. See Figure HYD-L-18. Examine the graph and shade in areas where you have water surplus, water shortage, shortage use and recharge, and runoff.

Form hypotheses on how closely other variables may be correlated with the water balance. Use the GLOBE Data Server to investigate your hypotheses.

1. Examine the GLOBE soil moisture data from the site where you modeled water balance. What correlation can you find between your model and the soil moisture data?
2. Compare the GLOBE biomass data from the site where you model water balance. How closely do they compare? Do times of greatest biomass occur at the times of greatest water availability?
3. Graph your measurements of water chemistry. Are there any indications of changes in water balance which may affect the quality of a water body?

Figure HYD-L-18: Example Graph for Precipitation, Water Needed (PE), and Actual Evapotranspiration



Hydrology Investigation

Water Balance Table Work Sheet

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Precipitation (mm)													
Water Needed (PE in mm)													
Extra Water													
Extra Water Needed													
Water in Storage													
Water Shortage													
Runoff													
Temperature (avg in Celsius)													

Example: Completed Water Balance Table (data from Mt. Lemmon, AZ, USA)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Precipitation (mm)	69	23	98	56	9	23	183	71	23	32	68	54	
Water Needed (PE in mm)	13	7	16	33	64	99	101	96	86	60	27	7	
Extra Water	56	16	82	23			82				41	47	
Extra Water Needed					55	76		25	63	28			
Water in Storage	56	72	100	100	45	0	82	57	0	0	41	88	
Water Shortage						31			6	28			
Runoff			54	23									
Actual Evapotranspiration	13	7	16	33	64	68	101	96	80	32	27	7	
Temperature (avg in Celsius)	2	2	4	8	12	17	18	17	16	12	7	3	

Hydrology Investigation

Calculating Potential Evapotranspiration Work Sheet

This work sheet will allow you to calculate the Potential Evapotranspiration (PE) for any site using the temperature and latitude data from the GLOBE server. Potential Evapotranspiration may then be used in the Water Balance Activity.

Step 1

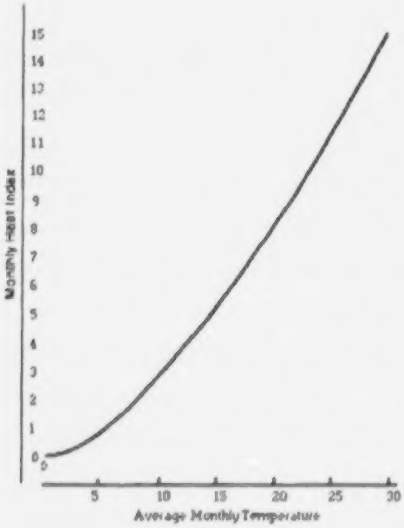
Find the Average Monthly Temperature for your site using the GLOBE data server.

Average Monthly Temperature:

Jan___Feb___Mar___Apr___May___Jun___Jul___Aug___Sep___Oct___Nov___Dec__

Step 2

Find the **Heat Index** for each month from the graph below.



Monthly Heat Index

Jan___Feb___Mar___Apr___May___Jun___Jul___Aug___Sep___Oct___Nov___Dec__

Step 3

Add the Monthly Heat Indexes together to get the Annual Heat Index.

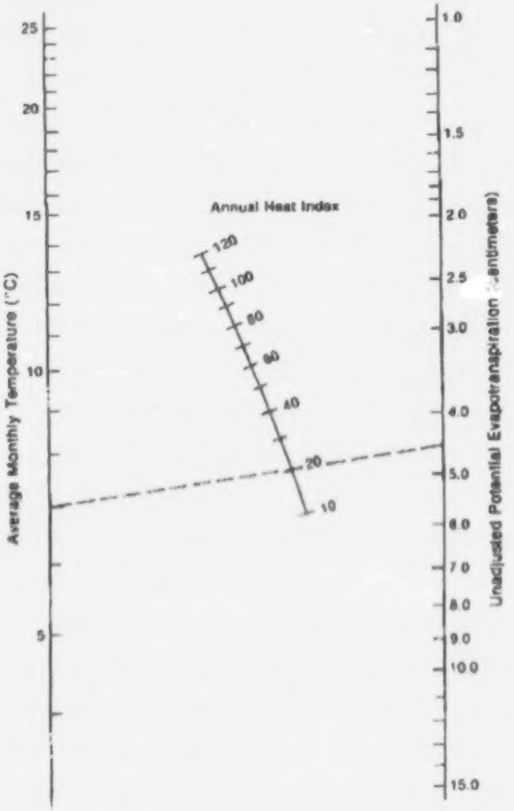
Annual Heat Index:________

Step 4

Using the **Annual Heat Index** and the **Average Monthly Temperature** for each month, find the **Unadjusted Potential Evapotranspiration** from the appropriate graph below.

NOTE: If the average temperature for the month is below 0, the Unadjusted Potential Evapotranspiration for that month is 0. If the average temperature for the month is greater than 26.5, use the Unadjusted Potential Evapotranspiration for High Temperatures graph below.

Unadjusted Potential Evapotranspiration



Note: To use the graph above, find your Average Monthly Temperature on the left and your Annual Heat Index in the center. Make a straight line joining the 2 points and continuing on until you cross the Unadjusted Potential Evapotranspiration line on the right. Read your Unadjusted PE from this line and record below. For higher temperatures, use the graph below to read your Unadjusted PE directly from the Temperature.

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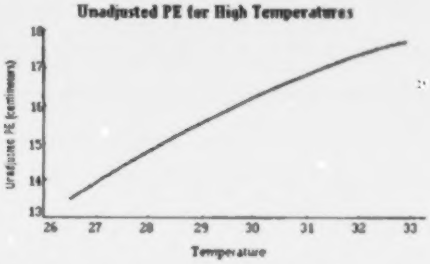


Unadjusted Potential Evapotranspiration for each month

Jan__Feb__Mar__Apr__May__Jun__Jul__Aug__Sep__Oct__Nov__Dec__

Step 5

Record the **Correction Factor** for each month from the table below.

Jan__Feb__Mar__Apr__May__Jun__Jul__Aug__Sep__Oct__Nov__Dec__

Step 6

Multiply the **Correction Factor** by the **Unadjusted PE** to find the **Potential Evapotranspiration.**

Potential Evapotranspiration

Jan__Feb__Mar__Apr__May__Jun__Jul__Aug__Sep__Oct__Nov__Dec__

Daylight Correction Factors for Potential Evapotranspiration

Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10 N	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
20 N	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
30 N	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
40 N	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
50 N	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70
10 S	1.08	0.97	1.05	0.99	1.01	0.96	1.00	1.01	1.00	1.06	1.05	1.10
20 S	1.14	1.00	1.05	0.97	0.96	0.91	0.95	0.99	1.00	1.08	1.09	1.15
30 S	1.20	1.03	1.06	0.95	0.92	0.85	0.90	0.96	1.00	1.12	1.14	1.21
40 S	1.27	1.06	1.07	0.93	0.86	0.78	0.84	0.92	1.00	1.15	1.20	1.29
50 S	1.37	1.12	1.08	0.89	0.77	0.67	0.74	0.88	0.99	1.19	1.29	1.41

Using the Table: For each month, look up the latitude of the site and the name of the month in the table above to find the Correction Factor for each month.

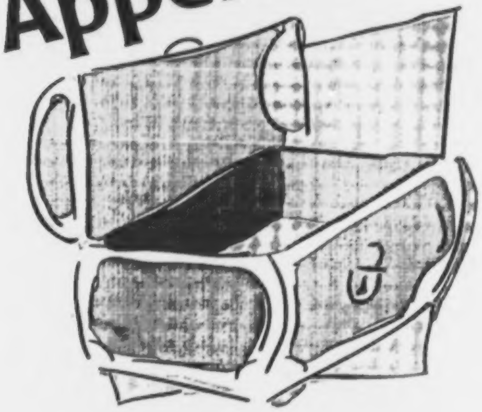
Note: The correction factors for latitude 50 N are used for all latitudes father to the north. The correction factors for latitude 50 S are used for all latitudes farther to the south.

Step 7

Record the PE in the appropriate row of your Water Balance Table.

*Adapted from Muller, Robert A and Oberlander, T. (1978) *Physical Geography Today: A Portrait of a Planet*, Random House.

Appendix



Data Work Sheet

Calibration Data Work Sheet

Contour Line Basics

Graphs for Duplication

Glossary

GLOBE Web Data Entry Sheets

Hydrology Investigation

Data Work Sheet

School name: ______________________________

Student group: ______________________________

Site Name: ______________________________

Sample collection date: ______ time: ______ (hours and minutes) check one: UT___ Local ___

Transparency

Cloud cover (check one): ____ clear ____ scattered ____ broken ____ overcast

Secchi Disk:

Observer 1: Length of rope: when disk disappears: ______ m when disk reappears: ______ m

Distance from where the Observer 1 marked the rope to the Water Surface: __________ m

Observer 2: Length of rope: when disk disappears: ______ m when disk reappears: ______ m

Distance from where the Observer 2 marked the rope to the Water Surface: __________ m

Observer 3: Length of rope: when disk disappears: ______ m when disk reappears: ______ m

Distance from where the Observer 3 marked the rope to the Water Surface: __________ m

Turbidity Tube:

Water line in tube when image disappears:

Observer 1: ______ cm Observer 2: ______ cm Observer 3: ______ cm

Water Temperature

Observer 1: ______ °C Observer 2: ______ °C Observer 3: ______ °C Average: ______ °C

Dissolved Oxygen

Observer 1: ______ mg/L Observer 2: ______ mg/L Observer 3: ______ mg/L Average: ______ mg/L

Kit manufacturer and model: ______________________________

pH

Measurement method: _____paper _____pen _____ meter

Value of buffers at site: pH 4: ______ pH 7: ______ pH 10: ______

Observer 1: ______ Observer 2: ______ Observer 3: ______ Average: ______

Conductivity

Conductivity Standard: ________ MicroSiemens/cm (µS/cm)

Observer 1: _____ µS/cm Observer 2: _____ µS/cm Observer 3: _____ µS/cm Average: _____ µS/cm

Data Work Sheet (page 2)

Salinity

Tide Information

Time of tide before measurement: ______________ hours and minutes

Check one: High Tide ___ Low Tide___ Check one: UT _____ Local time_____

Time of tide after measurement: ______________ hours and minutes

Check one: High Tide ___ Low Tide___ Check one: UT _____ Local time_____

Place where these tides occur: ____

Salinity (Hydrometer Method)

	Observer 1	Observer 2	Observer 3
Temperature of water in the cylinder:	________ °C	________ °C	________ °C
Specific Gravity:	________	________	________
Salinity of Sample:	________ ppt	________ ppt	________ ppt

Average Salinity: ________ ppt

Optional Salinity Titration

Salinity of Sample: Observer 1: ______ ppt Observer 2: ______ ppt Observer 3: ______ ppt

Average Salinity: ______ ppt

Kit manufacturer and model: ____

Alkalinity

For kits that read alkalinity directly

Observer 1: ____ mg/L as $CaCO_3$ Observer 2: ____ mg/L as $CaCO_3$ Observer 3: ____ mg/L as $CaCO_3$

Average: ______ mg/L as $CaCO_3$

Hach kits or other kits in which drops are counted:

	Observer 1	Observer 2	Observer 3	Average
Number of drops	_______drops	_______ drops	_______drops	_______ drops
Conversion constant for your kit and protocol:	x______	x______	x______	x______
Total Alkalinity (mg/L as $CaCO_3$)	=______mg/L	=______ mg/L	=______mg/L	=______ mg/L

Kit manufacturer and model: ____

Nitrate

Observer 1: ______ mg/L NO_3^- - N + NO_2^- - N ______ mg/L NO_2^- - N

Observer 2: ______ mg/L NO_3^- - N + NO_2^- - N ______ mg/L NO_2^- - N

Observer 3: ______ mg/L NO_3^- - N + NO_2^- - N ______ mg/L NO_2^- - N

Average: ______ mg/L NO_3^- - N + NO_2^- - N ______ mg/L NO_2^- - N

Kit manufacturer and model: ____________________________

Hydrology Investigation

Calibration Data Work Sheet

School name: ______________________________

Student group: ______________________________

Date: ________

Dissolved Oxygen:

Temperature of distilled water: ______C; Elevation of your site: _____meters

Dissolved Oxygen for the shaken distilled water:

Observer 1: _____ mg/L Observer 2: _____ mg/L Observer 3: _____ mg/L Average: ______mg/L

Solubility of oxygen in water for your temperature at sea level from Table 3-1.		Calibration value for your elevation from Table 3-2.		Expected value for DO in your distilled water:
______________mg/L	x	______________	=	_________mg/L

Kit manufacturer and model:______________________________

Salinity

Salinity of Standard: Observer 1: ______ ppt Observer 2: ______ ppt Observer 3: ______ ppt

Average Salinity: ______ ppt

Kit manufacturer and model:______________________________

Alkalinity

For Baking Soda Standard

For kits that read alkalinity directly

Observer 1: ____ mg/L as $CaCO_3$ Observer 2: ____ mg/L as $CaCO_3$ Observer 3: ____ mg/L as $CaCO_3$

Average: ______ mg/L as $CaCO_3$

Hach kits or other kits in which drops are counted:

	Observer 1	Observer 2	Observer 3	Average
Number of drops	_______drops	_______ drops	_______drops	_______ drops
Conversion constant for your kit and protocol:	x______	x______	x______	x______
Total Alkalinity (mg/L as $CaCO_3$):	=______mg/L	=_____ mg/L	=______mg/L	=______ mg/L

Kit manufacturer and model:______________________________

Nitrate

Observer 1: ____ mg/L NO_3^- - N Observer 2: ____ mg/L NO_3^- - N Observer 3: ____ mg/L NO_3^- - N

Average: ____ mg/L NO_3^- - N

Kit manufacturer and model:______________________________

Hydrology Investigation

Contour Line Basics

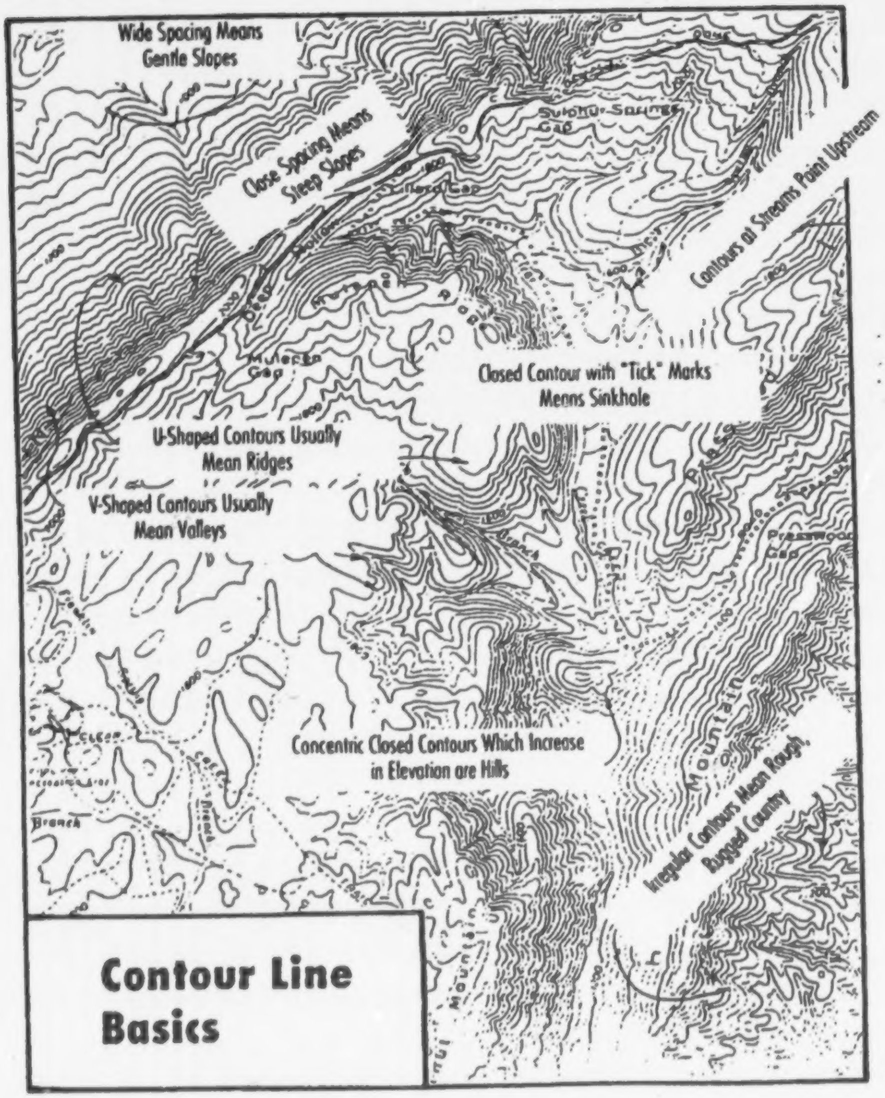

Wide Spacing Means Gentle Slopes
Close Spacing Means Steep Slopes
Sulphur Springs Gap
Contours at Streams Point Upstream
Mulecan Gap
Closed Contour with "Tick" Marks Means Sinkhole
U-Shaped Contours Usually Mean Ridges
V-Shaped Contours Usually Mean Valleys
Presswood Gap
Concentric Closed Contours Which Increase in Elevation are Hills
Irregular Contours Mean Rough, Rugged Country
Branch
Mountain
Contour Line Basics

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Figure HYD-A-1: GLOBE School in California, USA

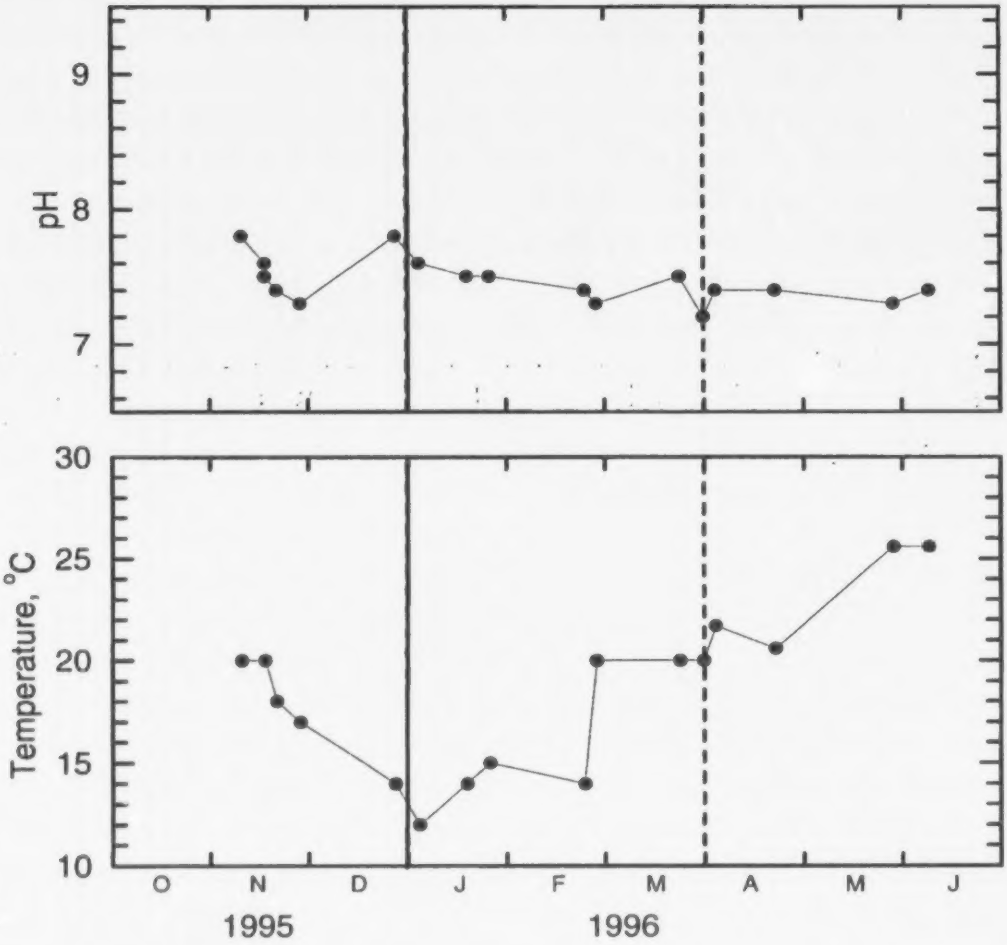


Figure HYD-A-2: GLOBE School in California, USA

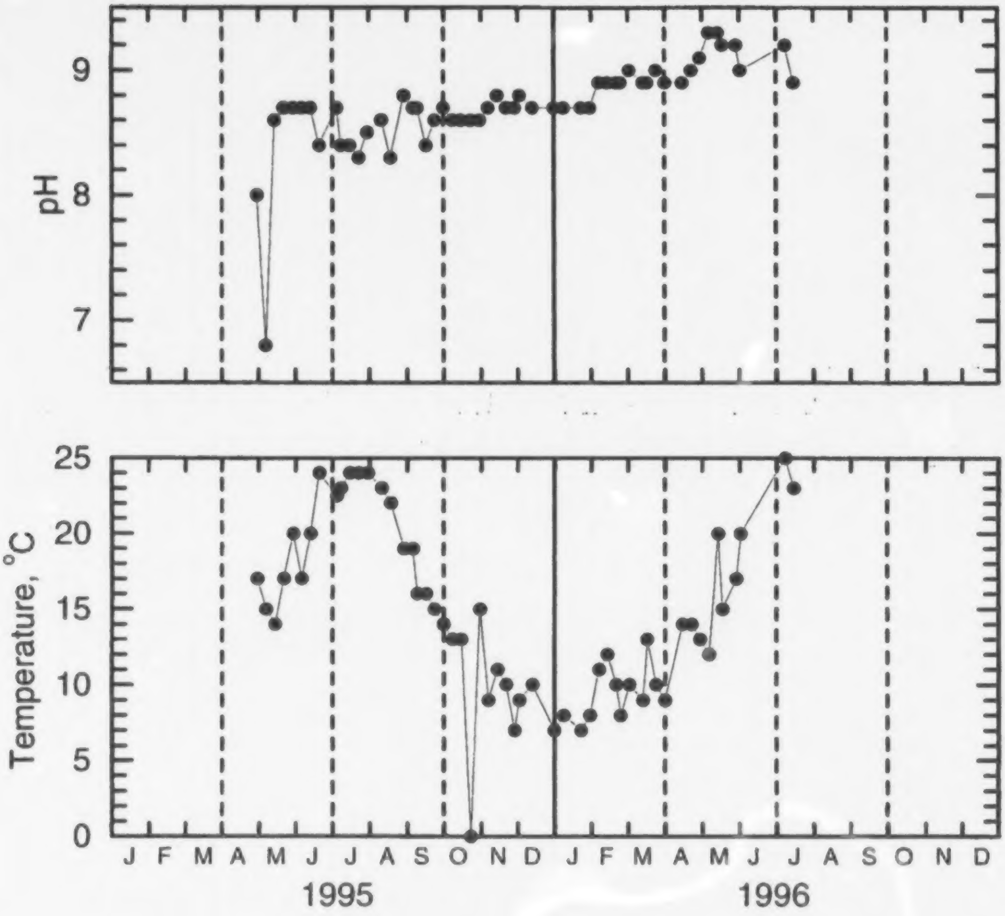


Figure HYD-A-3: GLOBE School in California, USA

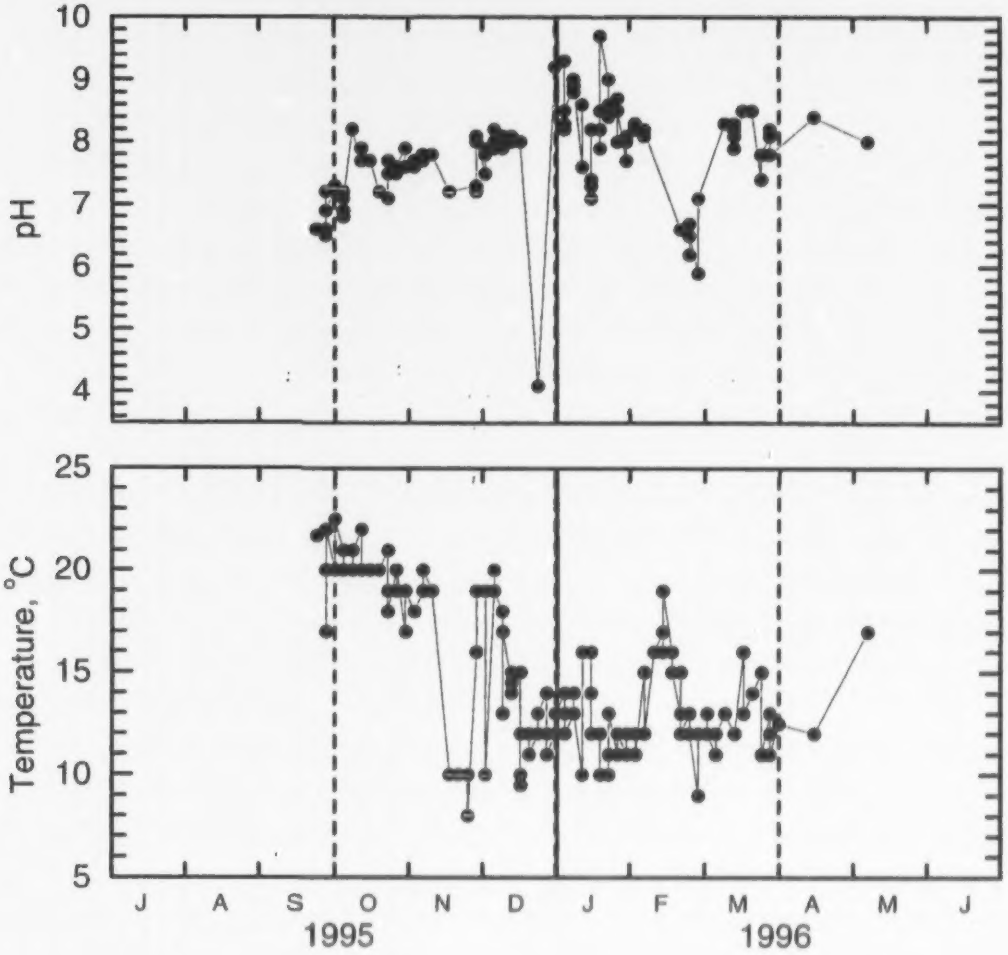


Figure HYD-A-4: GLOBE School in Florida, USA

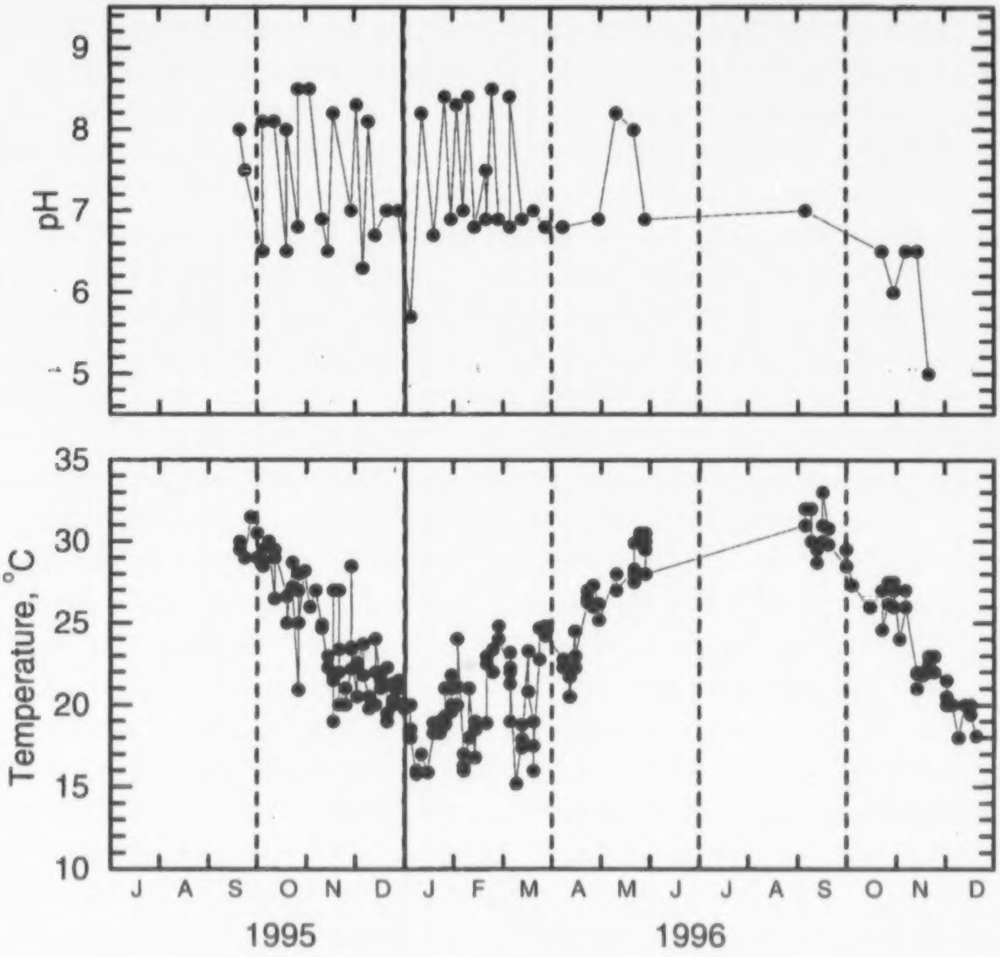
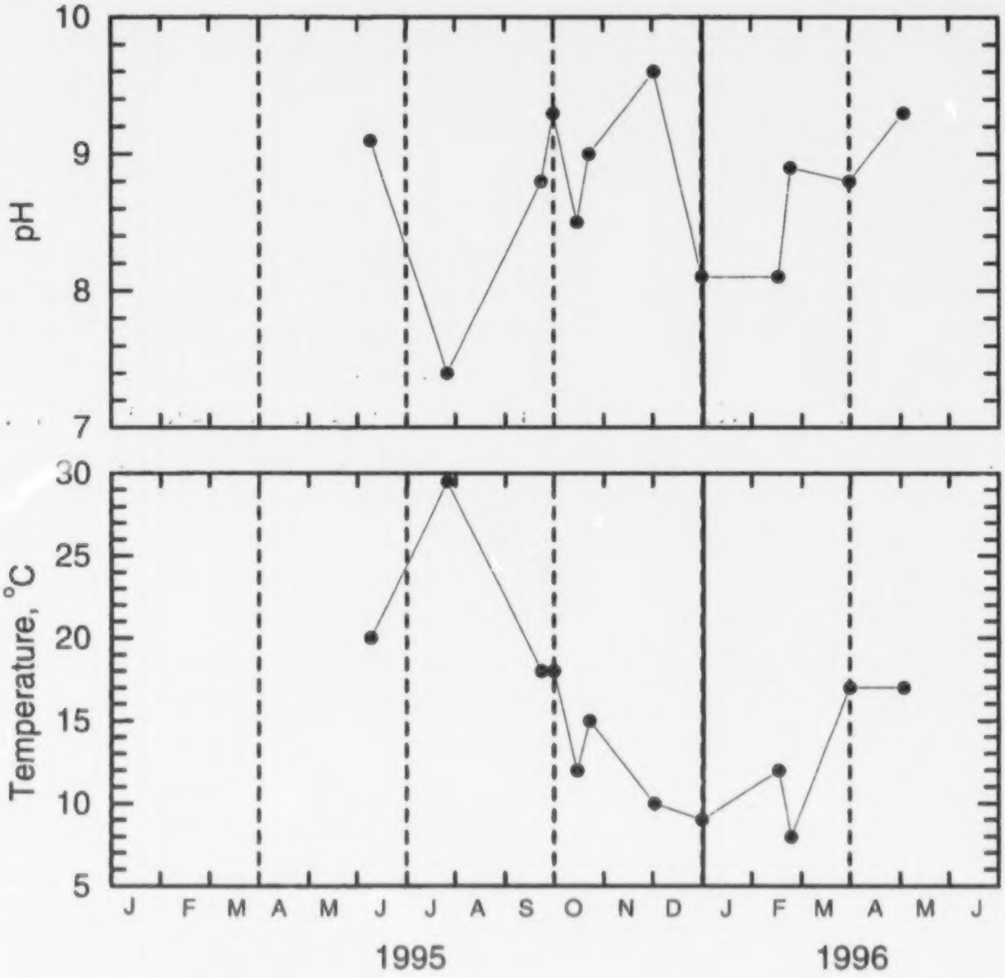
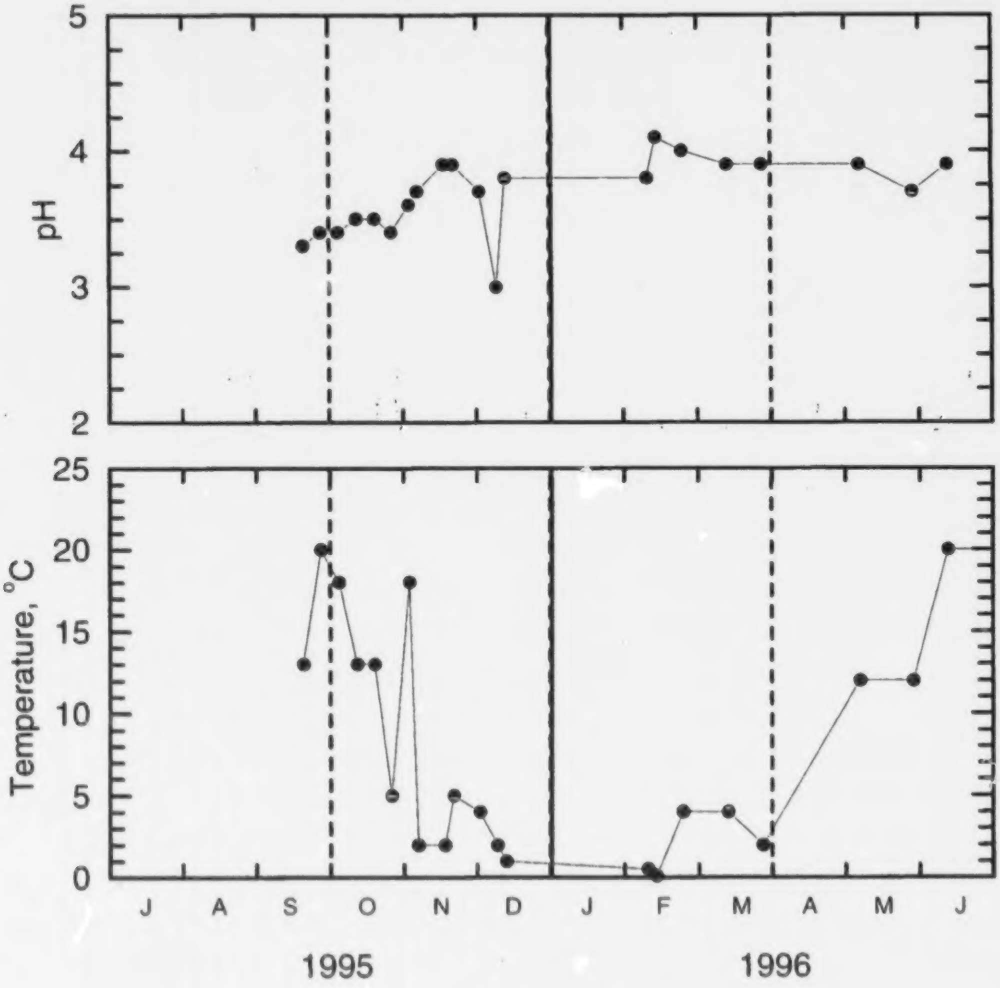


Figure HYD-A-5: GLOBE School in Washington, USA



Figur e HYD-A-7: GLOBE School in New Jersey , USA



Figur e HYD-A-8: GLOBE School in Japan

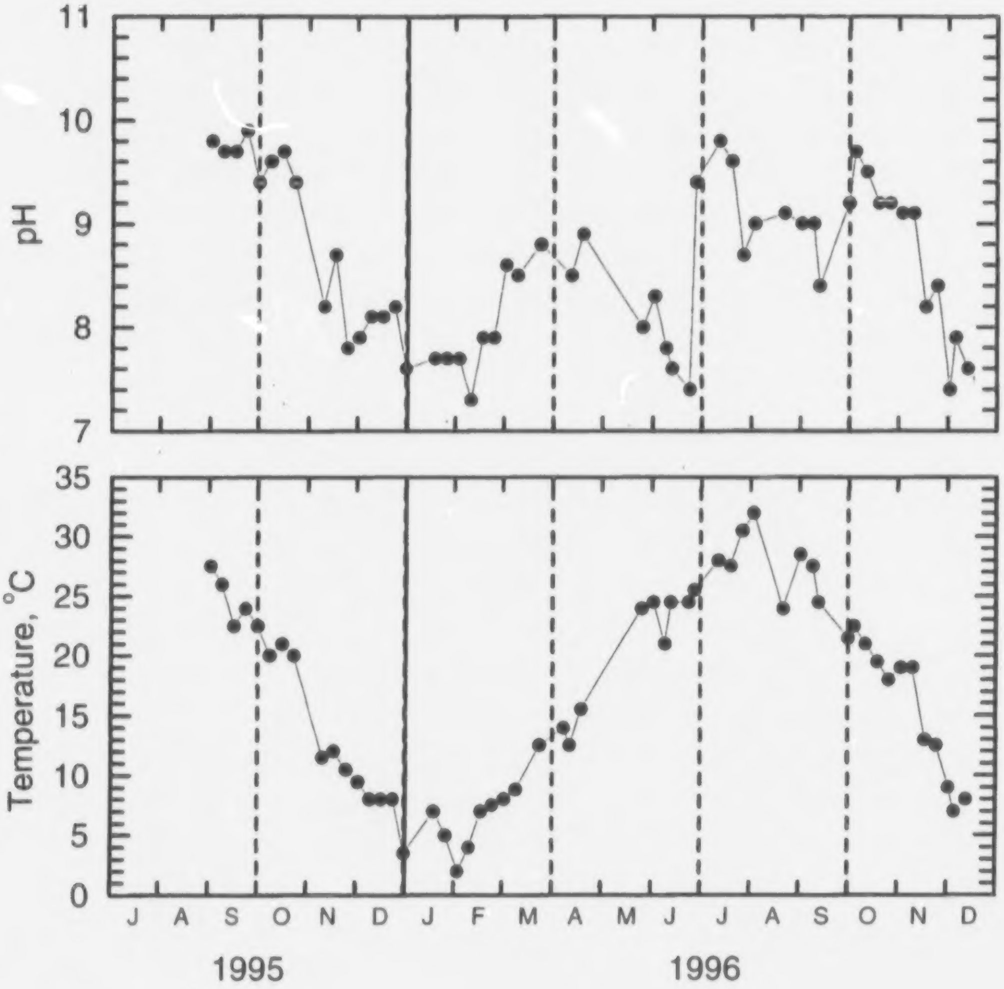


Figure HYD-A-9: GLOBE School in the Midwest of the United States

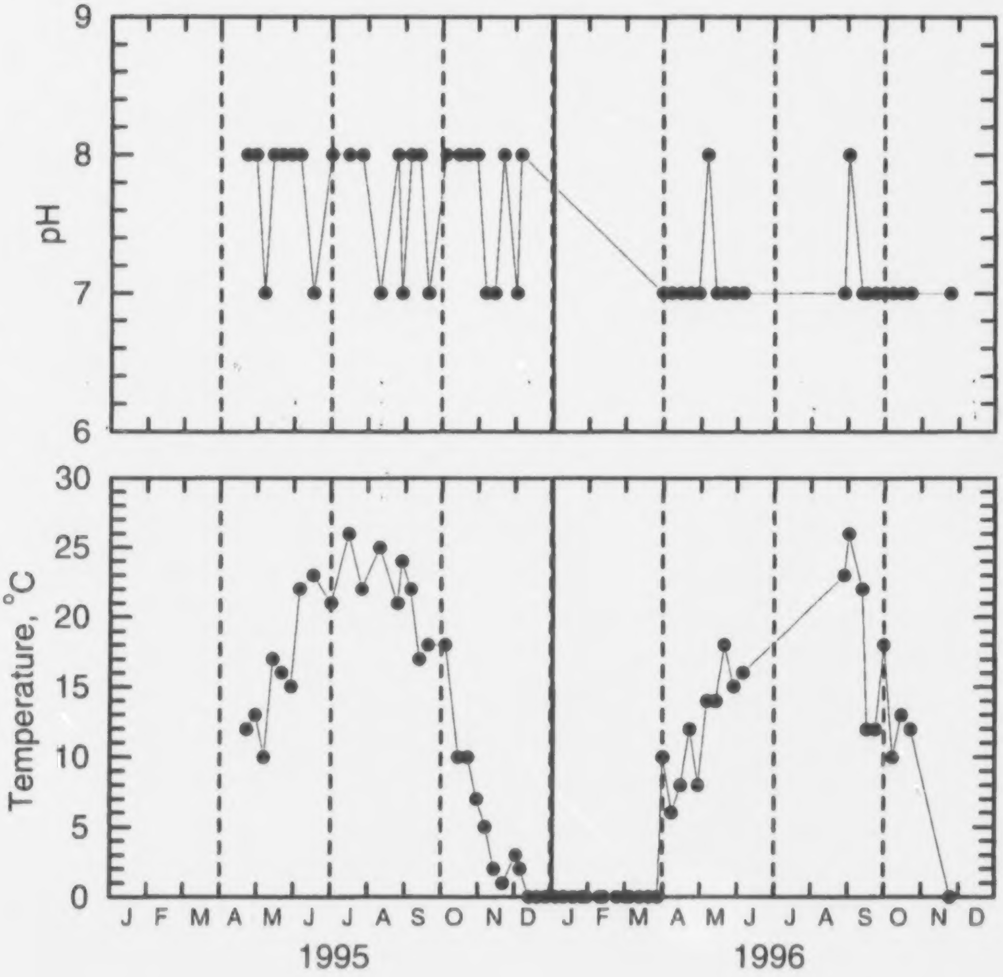
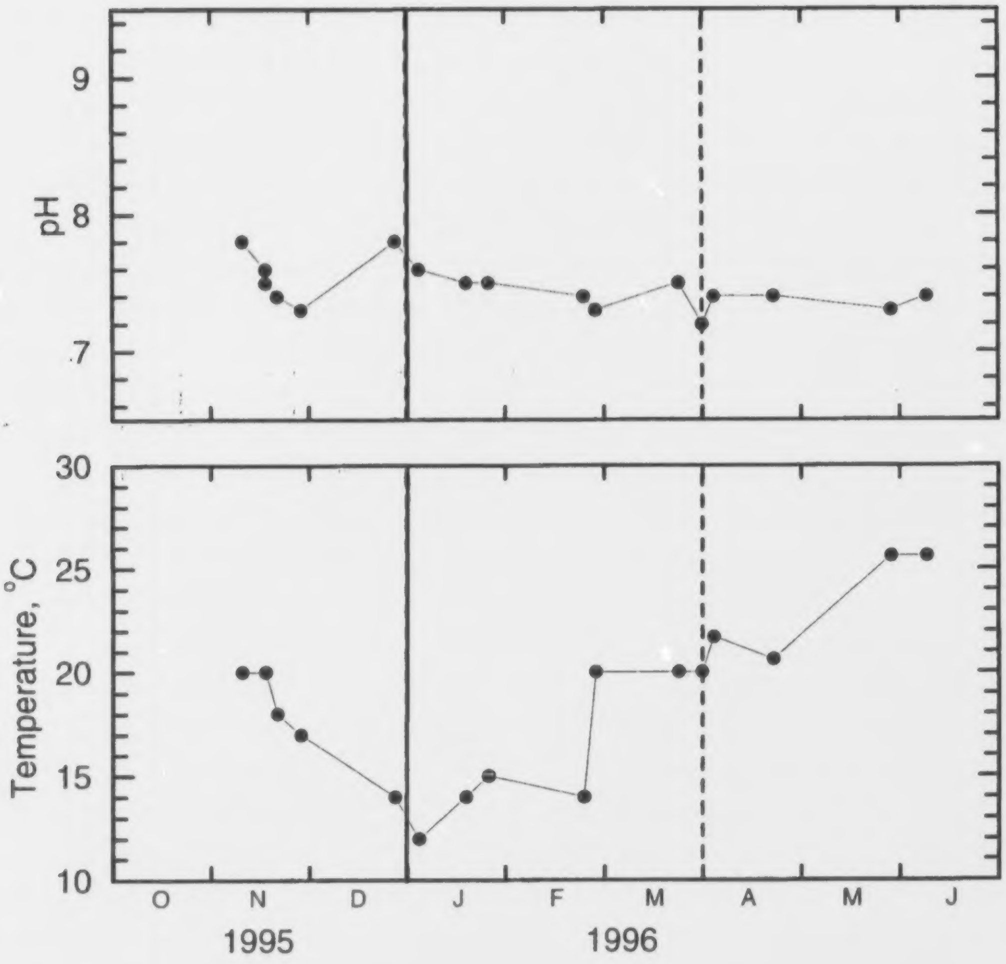
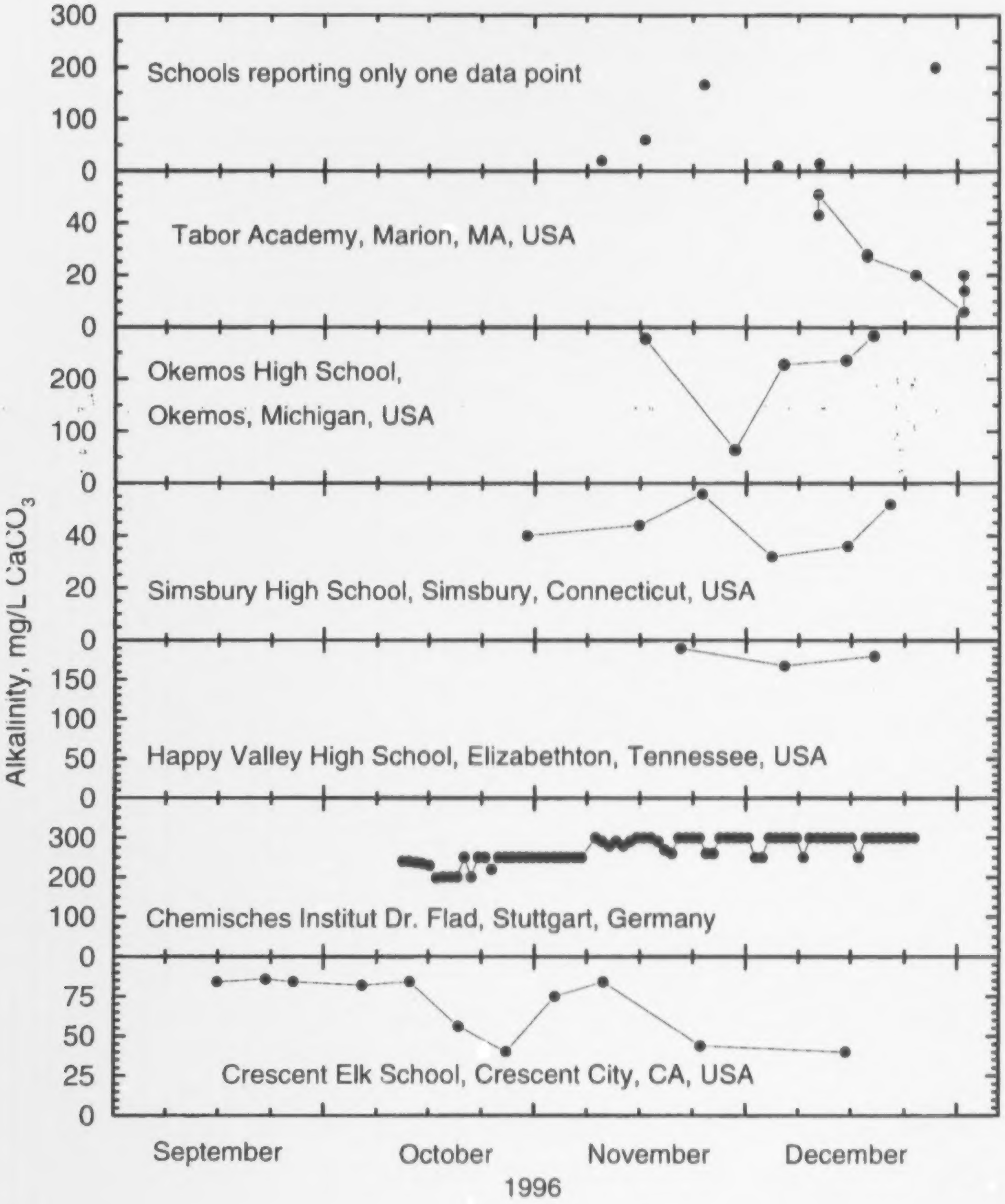


Figure HYD-A-10: GLOBE School in California, USA



Figur e HYD-A-11: GLOBE Alkalinity Data, September -December 1996



Figur e HYD-A-12: GLOBE Electrical Conductivity Data, September -December 1996

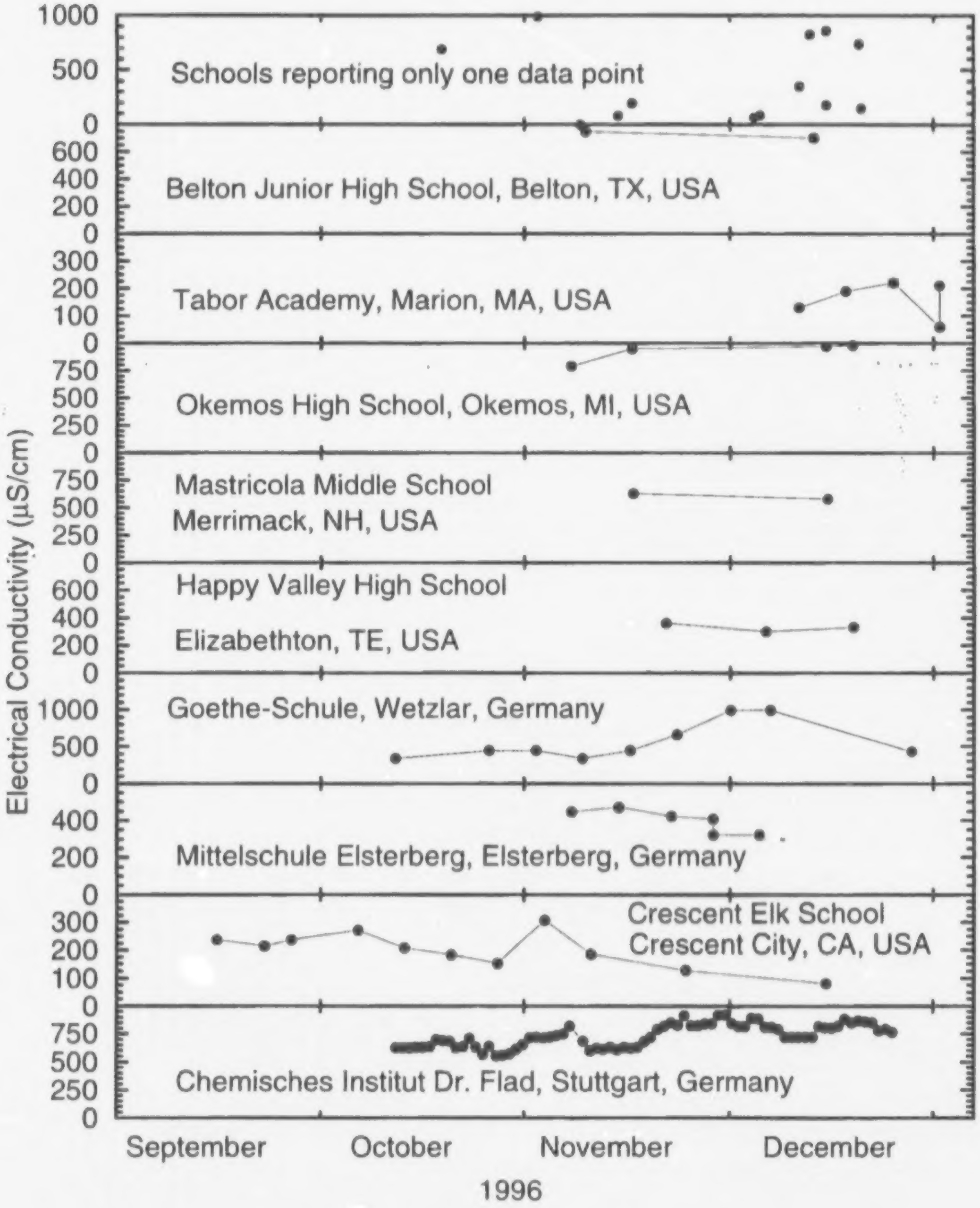
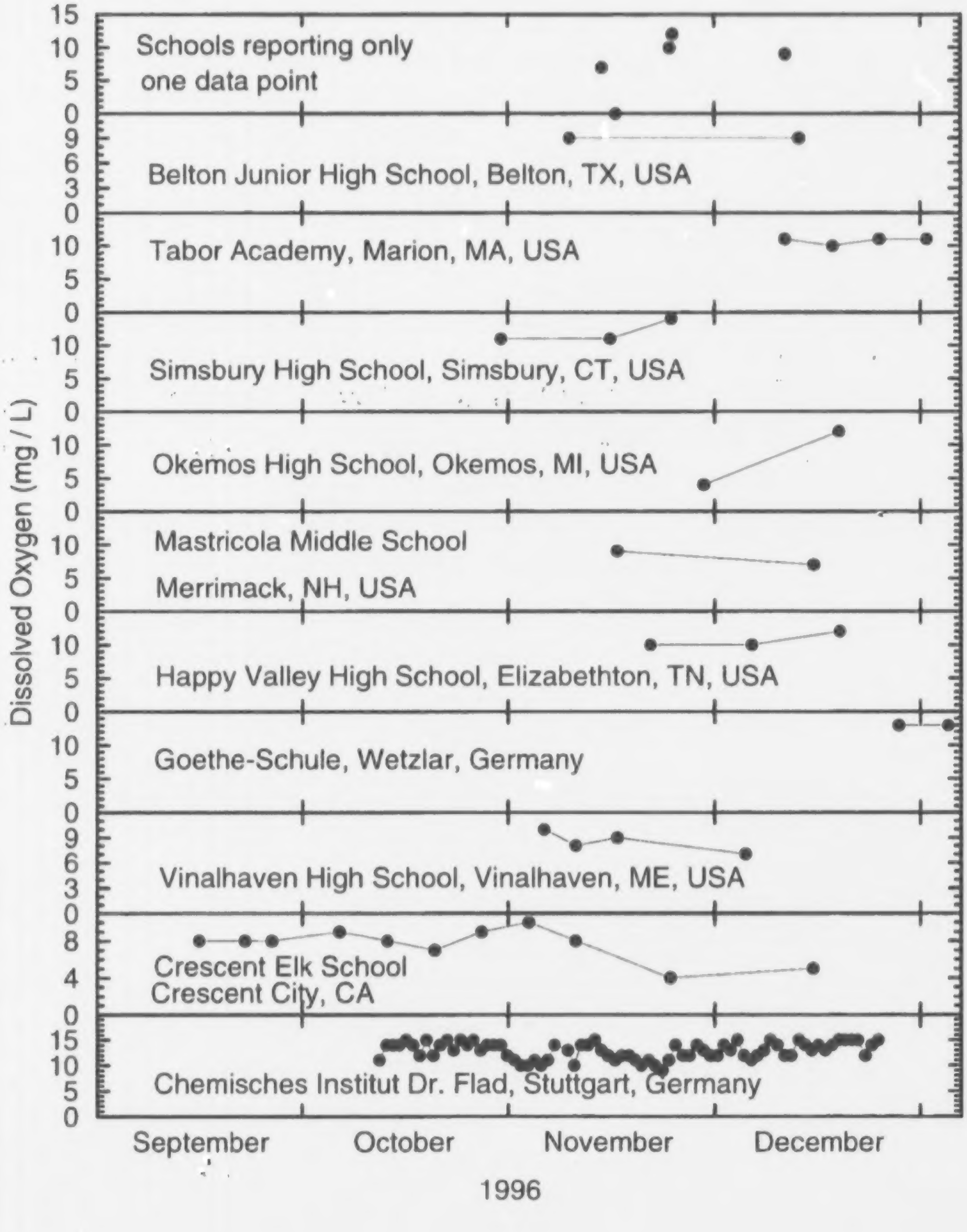
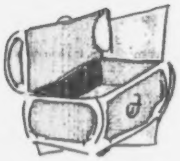


Figure HYD-A-13: GLOBE Dissolved Oxygen Data, September -December 1996



Glossary



accuracy

The closeness of a measured value to a true value (See precision).

acid

Any substance that can donate a hydrogen atom or proton (H^+) to any other substance.

acid rain

Rain characterized by pH values below 6.

acidic

Characterized by pH < 7.

acidity

1. The amount of strong base (e.g. Sodium Hydroxide) necessary to titrate a sample to a pH of around 10.3; measures the base neutralizing capacity of a water.

2. An acid quality or state. (Common Usage)

aerosols

Liquid or solid particles dispersed or suspended in the air.

alkaline

Characterized by pH > 7.

alkalinity

The amount of strong acid (e.g. Hydrochloric Acid) necessary to titrate a sample to a pH of around 4.5. Measures the acid neutralizing capacity of a water and is often reprinted as ppm $CaCO_3$.

aqueous

Containing or contained in water.

background concentration

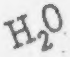
The level of chemicals present in a water due to natural processes rather than due to human contribution.

base

Any substance that accepts a proton (H^+) from another substance.

benthic

Pertaining to bottom dwelling water animals or plants.



brackish water

Water containing dissolved salts at a concentration less than seawater, but greater than fresh water. The concentration of dissolved salts is usually in the range 1000 - 10,000 ppm.

buffer solution

One that resists change in its pH when either hydroxide (OH^-) or protons (H^+) are added. The stable and known pH value of these solutions make them suitable for calibrating pH measuring devices.

calibration

To set or check an instrument against an index or standard of known value through some type of proportional or statistical relationship.

chlorinity

The chlorine concentration of a solution.

colorimetric method

Many procedures for measuring dissolved substances depend on color determination. The underlying assumption is that the intensity of the color is proportional to the concentration of the dissolved substance in question.

conductivity

The ability of an aqueous solution to carry an electrical current. Depends upon the concentration of dissolved salts (ions), the type of ions, and the temperature of the solution. Typical units are microSiemens/cm or micromhos/cm. (These are equivalent).

denitrification

The act or process of reducing nitrate to ammonia. Nitrite may be an intermediate product.

density

The ratio of the mass of a substance to its volume.

dissolved oxygen

The mass of molecular oxygen dissolved in a volume of water. The solubility of oxygen is affected nonlinearly by temperature; more oxygen can be dissolved in cold water than in hot water. The solubility of oxygen in water is also affected by pressure and salinity; salinity reduces the solubility of oxygen in water.

dissolved solids
Solid particles that have become liquid by immersion or dispersion in a liquid (e.g. salts).

enrichment
Making a water more productive (e.g. by adding nutrients).

eutrophication
A high level of productivity in a water body, often due to an increased supply of nutrients.

evaporation (of water)
Change from liquid to vapor at a temperature below the boiling point.

hydrologic cycle
The series of stages through which water passes from the atmosphere to the earth and returns to the atmosphere. Includes condensation to form clouds, precipitation, accumulation in soil or bodies of water and re-evaporation.

hypothesis
A tentative statement made to test its logical or empirical consequences.

in situ
Situated in its original natural place. (Latin)

lentic
Relating to, or living in standing water (lakes, ponds or swamps).

logarithmic scale
A scale in which each unit increment represents a tenfold increase or decrease.

lotic
Relating to, or living in actively moving water (streams or rivers).

microSiemens/cm
Metric unit of measurement for conductivity. Equivalent to micromhos/cm.

Micromhos/cm
Standard unit of measurement for conductivity. Equivalent to microSiemens/cm.

molar
Unit of measurement for concentration (moles per liter of solution).

molecule
The smallest fundamental unit (usually a group of atoms) of a chemical compound that can take part in a chemical reaction.

natural waters
Systems that typically consist of the sediments/minerals and the atmosphere as well as the aqueous phase; they almost always involve a portion of the biosphere.

neutral
Characterized by pH = 7.

nitrate
A salt of nitric acid (HNO_3). Nitrates are often highly soluble and can be reduced to form nitrites or ammonia.

nitrate-nitrogen
Concentrations of nitrate (NO_3^-) are often expressed as mass of nitrogen per volume of water.

nitrite
A salt of nitrous acid (HNO_2). Nitrites are often highly soluble and can be oxidized to form nitrates or reduced to form ammonia.

nitrite-nitrogen
Concentrations of nitrite (NO_2^-) are often expressed as mass of nitrogen per volume of water.

pH
The negative logarithm of the molar concentration of protons (H^+) in solution.

photosynthesis
The process in which the energy of sunlight is used by organisms, esp. green plants to synthesize carbohydrates from carbon dioxide and water.

ppm
Usually parts per million. (Equivalent to milligrams per Liter in GLOBE calculations).

ppm chlorinity
By weight, equal to milligrams of chlorine per Liter, with the assumption that one Liter of water weighs one kilogram.

ppt

Usually parts per thousand. (Equivalent to grams per Liter in GLOBE calculations).

precipitation

1. The falling products of condensation in the atmosphere. e.g. rain, snow, hail
2. Separation in solid form from a solution due to chemical or physical change (e.g. adding a reagent or lowering the temperature).

precision

A measurement for the degree of agreement between multiple analyses of a sample (See accuracy).

productivity

The formation of organic matter averaged over a period of time such as a day or a year.

proton

A positively charged elementary particle found in all atomic nuclei. The positively charged hydrogen atom (H^+).

reagent

A substance used to cause a reaction, especially to detect another substance.

reduce

In chemical terms, to change from a higher to a lower oxidation state (i.e. gain electrons).

runoff

The component of precipitation that appears as water, flowing in a stream or river.

saline water

Water containing salt or salts.

salinity

A measure of the concentration of dissolved salts, mainly sodium chloride, in brackish and salty water.

salts

Ionic compounds which in water solution yield positive (excluding H^+) and negative (excluding OH^-) ions ; the most common of which is sodium chloride, or "table salt".

saturated solution

A solution that contains the maximum amount of dissolved substances at a given temperature and pressure.

solubility

The relative capability of being dissolved.

solute

A substance that dissolves in another to form a solution.

solution

A homogeneous mixture containing two or more substances.

solvent

A substance that dissolves another to form a solution.

specific gravity

The ratio of the density of a substance to the density of water (at 25° C and 1 atmosphere).

standardization

To cause to conform to a standard.

standard

A measure with a value established through outside means for use in calibration; a known reference.

suboxic water

Very low levels of dissolved oxygen; denitrification occurs (nitrate is converted to ammonia).

suspended solids

Solid particles in a fluid that do not dissolve or settle out.

suspensions

A mixture in which very small particles of a solid remain suspended without dissolving.

tides

The periodic rise and fall of the waters of the ocean and its inlets, produced by the attraction of the moon and sun. Occurs about every 12 hours.

titrant

The reagent added in a titration.

titration

The process of ascertaining the quantity of a given constituent by addition of a liquid reagent of known strength, and measuring the volume of reagent necessary to convert the constituent through a given reaction.

topography

The surficial relief features of an area.

total dissolved solids

The total mass of solids remaining when a given volume of filtered water is evaporated to total dryness following an accepted protocol.

transparency

Having the property of transmitting rays of light through its substance so that bodies located behind can be distinctly seen.

turbid

Not clear, or transparent due to stirred up sediment.

water quality

A distinctive attribute or characteristic trait of water, described by physical, chemical, and biological properties.

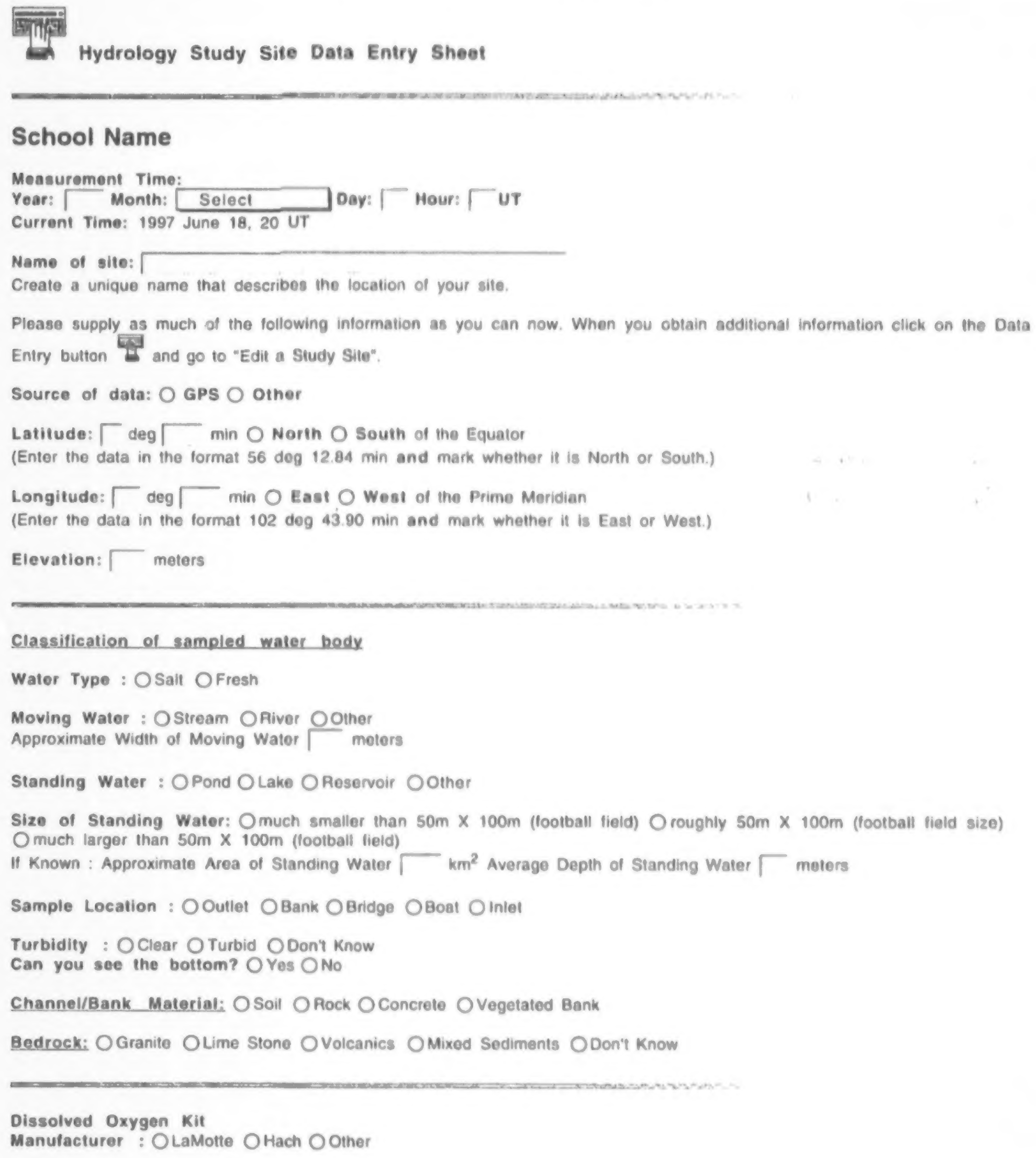
watershed

1. A line of separation between waters flowing to different rivers, basins or seas.
2. A term to mean the area drained by a river or stream. (Common Usage.)

water vapor

Water in the gaseous phase.

Hydrology Investigation



Hydrology Study Site Data Entry Sheet

School Name

Measurement Time:
Year: ☐ **Month:** Select **Day:** ☐ **Hour:** ☐ **UT**
Current Time: 1997 June 18, 20 UT

Name of site: ☐
Create a unique name that describes the location of your site.

Please supply as much of the following information as you can now. When you obtain additional information click on the Data Entry button and go to "Edit a Study Site".

Source of data: ○ **GPS** ○ **Other**

Latitude: ☐ deg ☐ min ○ **North** ○ **South** of the Equator
(Enter the data in the format 56 deg 12.84 min **and** mark whether it is North or South.)

Longitude: ☐ deg ☐ min ○ **East** ○ **West** of the Prime Meridian
(Enter the data in the format 102 deg 43.90 min **and** mark whether it is East or West.)

Elevation: ☐ meters

Classification of sampled water body

Water Type : ○ Salt ○ Fresh

Moving Water : ○ Stream ○ River ○ Other
Approximate Width of Moving Water ☐ meters

Standing Water : ○ Pond ○ Lake ○ Reservoir ○ Other

Size of Standing Water: ○ much smaller than 50m X 100m (football field) ○ roughly 50m X 100m (football field size) ○ much larger than 50m X 100m (football field)
If Known : Approximate Area of Standing Water ☐ km^2 Average Depth of Standing Water ☐ meters

Sample Location : ○ Outlet ○ Bank ○ Bridge ○ Boat ○ Inlet

Turbidity : ○ Clear ○ Turbid ○ Don't Know
Can you see the bottom? ○ Yes ○ No

Channel/Bank Material: ○ Soil ○ Rock ○ Concrete ○ Vegetated Bank

Bedrock: ○ Granite ○ Lime Stone ○ Volcanics ○ Mixed Sediments ○ Don't Know

Dissolved Oxygen Kit
Manufacturer : ○ LaMotte ○ Hach ○ Other

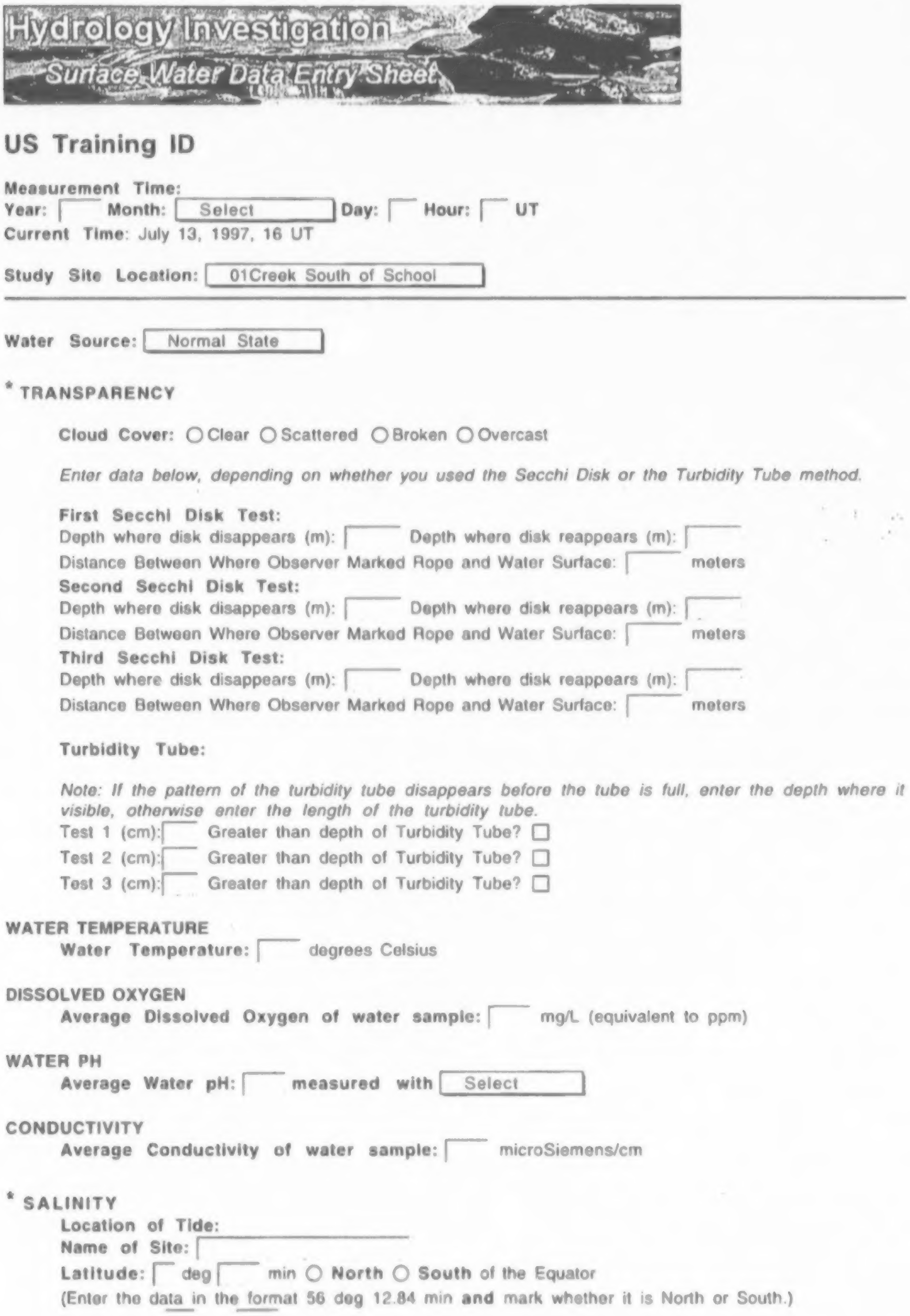
Model Name :

Alkalinity Kit
Manufacturer : LaMotte Hach Other
Model Name:
Conversion Constant :

Nitrate Kit
Manufacturer : LaMotte Hach Other
Model Name:

Salinity Titration Kit
Manufacturer : LaMotte Hach Other
Model Name:

NOAA/Forecast Systems Laboratory, Boulder,Colorado



Hydrology Investigation

Surface Water Data Entry Sheet

US Training ID

Measurement Time:
Year: **Month:** Select **Day:** **Hour:** UT
Current Time: July 13, 1997, 16 UT

Study Site Location: 01Creek South of School

Water Source: Normal State

*** TRANSPARENCY**

Cloud Cover: ○ Clear ○ Scattered ○ Broken ○ Overcast

Enter data below, depending on whether you used the Secchi Disk or the Turbidity Tube method.

First Secchi Disk Test:
Depth where disk disappears (m): Depth where disk reappears (m):
Distance Between Where Observer Marked Rope and Water Surface: meters
Second Secchi Disk Test:
Depth where disk disappears (m): Depth where disk reappears (m):
Distance Between Where Observer Marked Rope and Water Surface: meters
Third Secchi Disk Test:
Depth where disk disappears (m): Depth where disk reappears (m):
Distance Between Where Observer Marked Rope and Water Surface: meters

Turbidity Tube:

Note: If the pattern of the turbidity tube disappears before the tube is full, enter the depth where it visible, otherwise enter the length of the turbidity tube.
Test 1 (cm): Greater than depth of Turbidity Tube? ☐
Test 2 (cm): Greater than depth of Turbidity Tube? ☐
Test 3 (cm): Greater than depth of Turbidity Tube? ☐

WATER TEMPERATURE
Water Temperature: degrees Celsius

DISSOLVED OXYGEN
Average Dissolved Oxygen of water sample: mg/L (equivalent to ppm)

WATER PH
Average Water pH: **measured with** Select

CONDUCTIVITY
Average Conductivity of water sample: microSiemens/cm

*** SALINITY**
Location of Tide:
Name of Site:
Latitude: deg min ○ **North** ○ **South** of the Equator
(Enter the data in the format 56 deg 12.84 min **and** mark whether it is North or South.)

Time of High or Low Tide before Salinity Measurement (UT):
Hour: Minute: High Tide Low Tide
Time of High or Low Tide after Salinity Measurement (UT):
Hour: Minute: High Tide Low Tide

Enter data below, depending on whether you used the Hydrometer or the Titration method.

Hydrometer Method:
Temperature of water sample in 500mL tube (degrees C):
Specific Gravity of water sample:
Salinity of water sample: ppt
Average Salinity of water sample: ppt

Salinity Titration Method:
Salinity of water sample: ppt

ALKALINITY

Average Alkalinity of water sample: mg/L as $CaCO_3$

*** NITRATE**

Average Nitrate and Nitrite of water sample: mg/L nitrate nitrogen + nitrite nitrog
Average Nitrite of water sample: mg/L nitrite nitrogen

Comments:

* These inputs are new as of June, 1997. Find out more.

NOAA/Forecast Systems Laboratory, Boulder,Colorado

Soil Investigation

GLOBE DATABASE

A GLOBE™ Learning Investigation

Soil Investigation at a Glance

Protocols

- Measurements taken once at two or more Soil Characterization Sample Sites
  - top and bottom depths for each horizon in the soil profile
  - structure, color, consistence, texture
  - bulk density, particle size distribution, pH, and fertility (N, P, K) of samples taken from each horizon
  - soil infiltration
  - surface slope (in degrees)
- Measurements taken at the Soil Moisture Study Site:
  - soil moisture, 12 times per year
  - soil temperature, weekly
  - diurnal variation of soil temperature, seasonally
  - soil infiltration, seasonally

Suggested Sequence of Activities

Read *Welcome to the Soil Investigation*.
Copy and distribute to your students the scientists' letters and interviews.
Read the *Protocols* to learn precisely what is to be measured and how.
Read *The Learning Activities at a Glance* at the beginning of the *Learning Activities* section.
Do the first four activities before beginning the protocols.
Make copies of the data sheets in the *Appendix*.
Perform the *Soil Characterization Protocols*.
Perform the *Soil Moisture Protocol*.
Visit the GLOBE World Wide Web site with your students and review the data submission pages for Soils.
Submit your data to the GLOBE Student Data Server.
Do the remaining learning activities.

Special Notes

You may require help to dig your soil pit, if you choose to dig one.

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Scientists' Letters to Students

Duplicate and distribute to students

This investigation consists of two interrelated investigations. Soil Characterization, led by Dr. Elissa Levine, examines soil properties. Soil Moisture, led by Dr. Jim Washburne, examines the moisture in the soil.

Hello Students!

I am Elissa Levine and I am a Soil Scientist for the National Aeronautics and Space Administration (NASA). I am excited to be working with you.

People ask me, "Isn't soil just dirt? Who cares?" It's my favorite question. We take soils for granted, yet soils are among our most important natural resources. The ecosystem depends critically on soils. Soils allow water, energy and heat to flow through them, and they are essential for our food and clothing. We walk on soils, play on them, drive on them and construct homes, schools and buildings on them.

As a girl, I was fascinated by the color of soil, the way it felt, and all the rocks, roots and creatures living in it. As I grew up, I became concerned with feeding people and the proper use of our natural resources. So I studied soils.

What does a Soil Scientist do at NASA? I work at the Goddard Space Flight Center in Maryland. Our orbiting spacecraft carry sensors that send us images of the Earth, and I help to explain what the images reveal about the Earth's surface.

Together, we will determine what your soil looks like, why it looks that way, and how we can manage it for a healthy environment. You will closely examine soil samples from your study site.

Scientists will use your data to learn about the different soils across the Earth. Your data will help us to better interpret our satellite images and to better understand how systems interact on Earth and to predict what will happen to the soil in the future.

Have fun digging and exploring!

Elissa Levine

Dr. Elissa Levine
NASA/Goddard Space Flight Center
Greenbelt, Maryland, U.S.A.

Duplicate and distribute to students.

Dear Students,

Hi, my name is Jim Washburne. I am a research hydrologist at the University of Arizona in Tucson. Hydrology is the study of water and its movement through the atmosphere, soil and the underlying rocks. I am the scientist responsible for GLOBE soil moisture measurements.

When I was young, I was fascinated by how scientists discovered and tracked the movement of continents and the spreading of ocean floors from mid-ocean ridges. I feel the same level of excitement today in studying the Earth's water. New discoveries are being made daily but many questions remain unanswered.

People used to study the Earth piece by piece – looking at either soil, water, air, plants or animals. Now that we better realize how complex the Earth is, we know that it is important to study the whole system and the interconnections between the parts.

I am trying to understand how the water cycle works in dry areas of the world by asking questions like:

- When it rains, how much water remains in the soil and for how long?
- How does human activity affect the water cycle?
- How accurate are satellite data and can they be used in hydrologic models?

Scientists use sophisticated instruments and even satellites to measure soil moisture remotely. Only satellite data when linked with direct, long-term, hands-on ground observations can give us the valuable information we require. This is why we need your help in the field to make direct measurements of soil moisture. By monitoring your GLOBE sites, you will tell scientists what is actually happening on the ground.

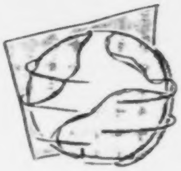
Each one of you can make a difference by making good observations and asking challenging questions. I look forward to working with you. Have fun exploring, measuring, and making sense of your data.

Sincerely,

Jim Washburne

Dr. James Washburne
Department of Hydrology and Water Resources
University of Arizona
Tucson, Arizona 85721-0011 USA
phone (520) 621-9944
fax: (520) 621-1422
email: jwash@hwr.arizona.edu

Meet Dr. Elissa Levine and Dr. Jim Washburne



Duplicate and distribute to students.

Dr. Levine: I'm a soil scientist for NASA's Goddard Space Flight Center in Greenbelt, Maryland. Goddard focuses on the Earth and Earth-orbiting satellites. I interpret images from the satellites that tell us about the environment. I also do soil modeling. We put all the soil information into a computer. We then factor in things like the type of vegetation and climate and write equations to describe how water moves through soil or how soils change over time. We try to predict what will happen.

Dr. Washburne: I'm a hydrologist at the University of Arizona. A hydrologist studies water. I'm studying the flows of water from one part of the planet to another. GLOBE fits into my work with NASA's Earth Observing System (EOS). Its goal is to launch the next generation of environmental resource satellites to collect data about the Earth. But as good as these satellites are, soil moisture is difficult to measure from space. There are really no good databases for regional or global soil moisture to check the satellite data.

GLOBE: Soil is just dirt. Why is it important?

Dr. Levine: My favorite question. Soils are one of the most important natural resources that we have. Every part of the ecosystem depends critically on soils. Soils filter water and remove its impurities. The food we eat, the clothes we wear, and many building materials all grow from the soil and depend on its conditions. Water and heat flow through it. It allows nutrients to be stored. Since the soil affects the entire ecosystem, I call it the great integrator.

Dr. Washburne: Soil moisture – the amount of water contained in the soil – is an important factor in determining the kinds of crops, lawns, shrubs and flowers we can grow. Scientists would like to know how soil moisture interacts with the atmosphere and climate.

GLOBE: What questions are you trying to answer with the GLOBE data?

Dr. Levine: What kinds of soils are there around the Earth? What are their properties? How do they relate to the other parts of the ecosystem?

GLOBE: What kind of data do you want from GLOBE students?

Dr. Levine: Students will examine samples of soil from their study site and study them in a variety of ways. I want them to become familiar with soil properties so we'll better understand how moisture flows in soil, how soil relates to vegetation, how it affects the climate, and so on. I'll put their data into my models.

Dr. Washburne: Students will learn how soil moisture varies by season throughout the world. To do that, we need as many observations as possible to compare with the satellite data and our computer models. Satellites, at best, can only measure soil moisture in the top five centimeters. We will use the student data to verify what the satellites measure with what's actually on the ground.

GLOBE: *Why do you need students to collect this data? Why can't you just get scientists to gather it?*

Dr. Levine: There aren't enough scientists. There are many different kinds of soil on the Earth. Most research has been in agricultural areas. But there are urban areas, forested areas, arid areas and many other places for which we have little data.

Dr. Washburne: When scientists do a careful study of soil moisture somewhere, that is only one measurement at one site at one time. GLOBE students represent a vast network of soil moisture and related observations that eclipses any past effort.

GLOBE: *Have students collected data before for soil investigations?*

Dr. Levine: Not at this level. Most work has been done by individual scientists, never by this great worldwide sampling effort.

Dr. Washburne: I'm confident students can do it. The soil-moisture observation is simple. You dig up some soil, weigh it, dry it, then weigh it again. The difference is how much water has been dried out of the soil.

GLOBE: *You are both involved with NASA, yet the common perception is that NASA explores space. Is it also involved in Earth exploration?*

Dr. Levine: Yes. NASA looks at Earth as a planet, just like any other planet. NASA's Mission to Planet Earth is one of its most important projects. Only by observing the Earth from space can you monitor its many ecosystems and study the interconnections between them.

GLOBE: *Tell us a little about yourselves. Where did you grow up and go to school?*

Dr. Levine: Long Island, in the suburbs of New York City. My parents used to take me to parks, caves and petrified forests in upstate New York, and I became interested in natural areas. I always had this fantasy to live in a cave or under a waterfall. That was the beginning. I liked math and science in school. In college in the early '70s, I studied psychology for a couple of years, but I got a strong idealistic desire to preserve nature and help feed people. So I went to an agricultural school where I became interested in soils. In the summers, I did soil mapping and conservation work. When I finished school there, I went for my Masters' and Ph.D. degrees. This is where I really began to explore soil profiles in different parts of the US and the world. I was fascinated by how each soil develops its own unique properties that determine how it can be used. As I learned more about soil properties and soil formation, I began to put it all together in mathematical models.

GLOBE: *We don't see enough women in science.*

Dr. Levine: I'm glad that you brought that up. In high school, I was interested in science. But I didn't really trust that I could do it.

GLOBE: *Because you were a woman?*

Dr. Levine: That's what I think. Most people around me are men, and my experience has shown that there is generally a difference in the way we think. I tend to see the big picture, while many men around me tend to focus better on the details. So together we complement each other. But we need more women in science because it's unbalanced now. We need to tie all these systems together.

GLOBE: *Were you discriminated against because you're a woman?*

Dr. Levine: In high school, I got As and Bs in science and math, but I didn't have much guidance from the people around me, or many role models to help me. I wanted to have a good career, but to also have a family. I learned that if I followed my heart, things will work out. I am now a scientist and I have two wonderful children. People in science who have families add a very positive dimension. A family gives you purpose. I'm concerned about the Earth because I want my children to have happy and healthy lives. You can have both a family and career.

GLOBE: *Are there many women in the field now?*

Dr. Levine: Yes, and more are entering the field. There is an organization called the Association of Women in Soil Science, and women get together at international soil-science meetings. We tend to have similar experiences.

GLOBE: *Where did you grow up, Dr. Washburne?*

Dr. Washburne: I was born in Denver, Colorado, and stayed in the state through high school. I spent a lot of time in the Colorado Rockies hiking and working on ranches. Like many states in the western U.S., Colorado is semi-arid and you usually have to irrigate crops or water lawns. So water's been an element in my life for a long time. My goal in college was to major in physics, but since I grew up in the Rocky Mountains, with their abundant outcroppings as testament to the great forces of nature, I was drawn into a geology major as well. In graduate school, I studied geophysics at Colorado School of Mines in Golden, Colorado. I learned to use electrical measurements to remotely sense below the surface of the Earth for mineral and oil deposits. After several good years, the exploration industry declined and I was laid off, I returned to school to get a Ph.D. in the exciting and interdisciplinary field of hydrology.

GLOBE: *When did you first become interested in science and why?*

Dr. Washburne: The methodology of science, of carefully studying something, is very satisfying to me. I have always enjoyed science and unraveling the relationships between the things around me, but it was not until I took my first physics class that I fully appreciated the simplicity and power science has to explain our universe. You will find that becoming a scientist requires a strong commitment. I find science satisfying because it helps to explain nature and is challenging - like an unfinished mystery.

GLOBE: *If there was one question that you could answer in your field, what would it be?*

Dr. Levine: Soils have different layers, colors, shapes and textures – all kinds of different things and different organisms living in them. How do they all fit together in this complex system?

Dr. Washburne: What will be our effect on the climate over the next hundred years? If the climate warms up, the hydrologic cycle might become more active, but we really do not have all the answers yet.

GLOBE: *What are the rewards of science?*

Dr. Washburne: I find all Earth science, particularly hydrology, to be very satisfying and valuable to society. What attracts many of us to science is not necessarily the global discoveries as much as the day-to-day discoveries, revelations, and satisfaction that the search and the sharing of what we know brings to us.

I'm also gratified that there are important social and policy issues that hinge on my work. My satisfaction comes from understanding something clearly, and it is amplified when you know this something has great ramifications. For instance, my study of soil moisture is part of a larger effort to improve the climate models scientists use to understand human impact on global temperature. The social and economic ramifications are enormous.

But everyday satisfactions are important, too. Knowing why the old farm road gets so slippery when moisture gets mixed in with the clay or understanding where the colors of the rainbow come from can be richly rewarding to you or me. Science is a process with many exciting (re)discoveries along the way that are new and meaningful to the individual. Don't forget to savor the small discoveries. They are as much the glue of the universe – the spice of life – as are all the grand old theories.

GLOBE: *Scientists all seem to have a healthy dose of curiosity. Is that something you identify with?*

Dr. Washburne: Definitely. It's important for scientists to ask questions. Scientists are no different from anyone else. I don't think there's anyone who can't become a scientist by applying themselves. In school, we are deluged with facts. From those facts, try to understand the fundamentals and apply them to issues that matter to you.

Despite all we do know, there's so much more to learn about the world and the way its elements interact. I think GLOBE students are lucky because they will be the ones to harvest the results of NASA's Mission to Planet Earth throughout their careers. It's very exciting that there's still so much to learn and understand about the world around us.

Dr. Levine: I know that I have a strong dose of curiosity. This curiosity is probably why scientists say: the more you learn, the more you know how little you know. I am especially curious about what new information about soils we are going to learn from the GLOBE student data.

GLOBE: *Do you have international colleagues?*

Dr. Levine: I do. Recently I was at a conference in China to study similar issues about soils that we're also studying in the U.S. I have also worked with people in Australia, Europe, Russia, South America and the deserts in Africa.

Dr. Washburne: I have colleagues in Europe and Latin America and have traveled to some far corners of the world. I am looking for collaborators from all over the world to work with GLOBE students and their observations.

GLOBE: *When you were growing up, did you have heroes?*

Dr. Washburne: I always wished I had grown up in Lewis and Clark's time or had been with Captain Cook in his voyage around the world. Even the simple mountain men were heroes to me. How exciting it would be to be among the first to explore previously uncharted territory, where every step you took would be a discovery unto itself.

GLOBE: *What's a typical day like for you? Do you work in labs?*

Dr. Levine: Although I am interested in field soils, much of my time is spent in front of a computer doing research, running models, writing and reading scientific articles, and answering email. When I do get to go in to the field, I go with a team of other scientists and we spend a week or two characterizing and monitoring different sites based on soils, vegetation, and climate. Then we bring samples back which are sent off to be analyzed. I use the data from the field work to test and create the models I use for my research.

Dr. Washburne: Surprisingly, I spend the majority of my time writing and reading about 40% and 10%, respectively during the average week. The 30% of my time I spend on the computer is divided between email, analysis, and programming. I would like to spend more time reading about what other people have done. That's important for scientists to do, and sometimes I only have time to skim abstracts. I spend ten percent of my day in meetings, talking with other scientists and devising strategies for various problems. If I get through a week when only 10% of my time is unclassified, then I am doing exceptionally well. What I like about my job is that every day is different.

GLOBE: *You said that students have not done this kind of work before. Is GLOBE unique?*

Dr. Levine: Oh, definitely. It's going to help us so much to understand soil properties. Having soils in grade school is great. It will help all people have a better appreciation of the importance of soils. I'm excited that soils will be an important part of their Earth systems studies. It should have been there all the time.

GLOBE: *What do you hope students will learn in GLOBE?*

Dr. Washburne: I hope they will better observe and understand the environment around them and appreciate the need to support scientific research – particularly to learn how people and nature can live in greater harmony.

GLOBE: *Why should a student enter soil science today?*

Dr. Levine: Soils are critical for survival. We need young scientists who understand how soils fit into the rest of the ecosystem and help us maintain our standard of living and have a healthy Earth to live on.

GLOBE: *Why should a student today become a hydrologist?*

Dr. Washburne: Hydrology is exciting and has many specializations. A very important one is investigating and cleaning up our ground water. This will take a lot of work. The global hydrology I'm working on is also important. NASA's launch of a new generation of Earth resources satellites will definitely generate many questions to be solved by today's students for years to come.

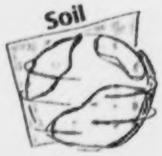
GLOBE: *Any advice for students in general and young women in particular who might be interested in pursuing Earth science?*

Dr. Levine: My number one advice for all students is to go outside and explore natural areas that are nearby. Look at flowers, look at the ground, feel the soil under their feet, dig a hole, and look at what's there. Once students appreciate the ecosystem, a lot of their other classes in math and science, even history and language will make more sense. So that's number one: Get outside.

To women I would say, we need you. We need to take our place next to men. We have a very important role to play. Both men and women need to look at the Earth through a more holistic, nurturing type of approach. Women can do anything they choose to and do it really well.

Dr. Washburne: It is important not to be narrowly focused. I urge students to get a broad background in whatever they're doing. In global hydrology, it's essential to understand soils, remote sensing, the atmosphere, meteorology, and how trees and plants interact with water. It's very interdisciplinary. Computers are important, and mathematics is the foundation for a lot of our work. Do what you enjoy doing the most, and don't feel that all the questions have been answered or are going to be answered anytime soon. Speak up and ask questions, because fundamentally that's what we do: ask questions and look for their answers.

Introduction



The Big Picture

Soils are a thin layer, called the *pedosphere*, on top of most of Earth's land surfaces. This thin layer is a precious natural resource. Soils so deeply affect every other part of the ecosystem that they often are called the "great integrator." Soils hold nutrients and water for plants and animals. Water is filtered and cleansed as it flows through soils. Soils affect the chemistry of the water and the amount of water that returns to the atmosphere to form rain. The foods we eat and most of the materials we use for paper, buildings, and clothing are dependent on soils. Understanding soil is important for knowing where to build our houses, roads, buildings, and playgrounds as well. This investigation guides you through measurements of soil characteristics, soil moisture, infiltration, and soil temperature.

One of the most important characteristics of any soil is how much water it contains. Either in the form of a vapor or a liquid, water occupies about one-fourth of the volume of a productive soil. If the soil gets too dry and is not covered by vegetation, it blows away in the wind. Yet if there is too much water, the ground becomes soggy and cannot sustain many crops or, for that matter, the foundations of buildings. The rate at which water flows into or infiltrates the surface determines how much water will runoff during a rainstorm. Dry, porous soils can absorb large amounts of rain and protect us from flash floods. Soil that is nearly saturated with water or slow to take up water can heighten the likelihood of flooding.

All terrestrial life is directly or indirectly dependent on sufficient levels of water in the soil. Soil moisture combines with other properties of the land and climate to determine what kinds of vegetation grow. Soil acts as a sponge and holds water for uptake by the roots of plants. Some soils are more effective at this than others. For example, in deserts with sandy soil which does not hold water well, cacti store their own water, while other trees send roots deep in the soil to tap water buried tens of meters below the surface.

Soil temperature acts much the same way to influence all living organisms. Soil temperature changes more slowly than that of the atmosphere. In many temperate regions the surface soil freezes in winter, but below a certain depth, the ground never freezes and the temperature is almost constant throughout the year. In some cold climates, a permanent layer of ice called permafrost is found below the soil surface. Soil acts to insulate the deeper layers of soil and whatever lives in them from the extremes of temperature variation.

Figure SOIL-I-1

Soil Properties That Change Over Time

Properties that change over minutes, hours, or days	*Properties that change over months or years*	*Properties that change over hundreds and thousands of years*
temperature moisture content composition of air in soil pores	soil pH soil color soil structure soil organic matter content soil fertility microorganisms density	kinds of minerals particle size distribution horizon formation

Both the temperature and moisture of the soil near the surface affect the atmosphere as heat and water vapor are exchanged between the land surface and the air. These affects are smaller than those of oceans, seas, and large lakes, but at times they significantly influence the weather. Hurricanes have been found to intensify instead of losing strength when they pass over ground that is already saturated with water. Meteorologists have found that their forecasts are sometimes improved if they factor soil conditions into their calculations. How surface soil temperature and moisture respond to changes in the atmosphere depends upon the characteristics of the surface of the soil and those of the underlying soil profile. In GLOBE, student measurements include many of the physical and chemical properties of soil which will provide insights into the role soil plays in climate.

Soil Composition and Formation

Soils are composed of three main ingredients: minerals of different sizes; organic materials from the remains of dead plants and animals; and open space that can be filled with water and air. A good soil for growing most plants should have about 45% minerals (with a mixture of sand, silt and clay), 5% organic matter, 25% air, and 25% water.

Soils are dynamic and change over time. Some properties, such as temperature and water content (a measure of soil moisture) change very quickly (over minutes and hours). Others, such as mineral transformations, occur very slowly over hundreds or thousands of years.

Soil formation (*pedogenesis*) and the properties of the soil are the result of five key factors. These factors are:

1. parent material – The material from which the soil is formed. Soil parent material could be bedrock, organic material, an old soil surface, or a deposit from water, wind, glaciers, volcanoes, or material moving down a slope.

2. climate – Heat, rain, ice, snow, wind, sunshine, and other environmental forces break down the parent material and affect how fast or slow soil processes go.

3. organisms – All plants and animals living in or on the soil (including micro-organisms and humans!). The amount of water and nutrients plants need affects the way soil forms. Animals living in the soil affect decomposition of waste materials and how soil materials will be moved around in the soil profile. The dead remains of plants and animals become *organic matter* which enriches the soil. The ways humans use soils affect soil formation.

4. topography – The location of a soil on a landscape can affect how the climatic processes impact it. Soils at the bottom of a hill will get more water than soils on the slopes, and soils on the slopes that directly face the sun will be drier than soils on slopes that do not.

5. time – All of the above factors assert themselves over time, often hundreds or thousands of years.

Soil Profiles

Due to the interaction of the five soil-forming factors, soils differ greatly. Each section of soil on a landscape has its own unique characteristics. The *face* of a soil, or the way it looks if you cut a section of it out of the ground, is called a *soil profile*, just like the profile of a person's face. When you learn to interpret it, the profile can tell you about the geology and climate history of the landscape over thousands of years, the archeological history of how humans used the soil, what the soil's properties are today, and the best way to use the soil. In a sense, each soil profile tells a story about the location where it is found.

To read some examples of these stories, see *Soils Around the World* at the end of this section.

Every soil profile is made up of layers called *soil horizons*. Soil horizons can be as thin as a few millimeters or thicker than a meter. You can identify the individual horizons because they will have different colors and different-shaped particles. They will feel different and have other properties that differ from those above or below them. Some soil horizons are the result of erosion. Soils are washed downstream and deposited over hundreds or thousands of years, creating extensive new layers of soil and gravel that can be identified in road cuts and trenches.

Soil scientists label horizons with a special code to identify them. Not all soils have the same horizons, and the horizons in your soil will depend on how it has formed. Some of the codes used to describe horizons are listed below:

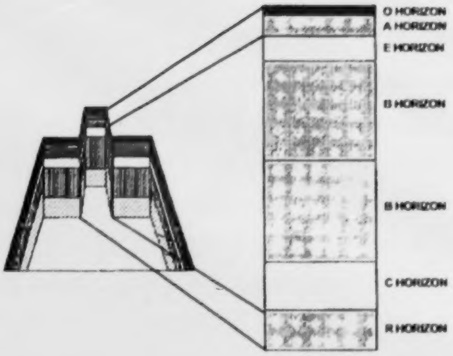
O Horizon

The O horizon is so named because it is made of *organic* material. This horizon is found on the soil surface and contains mostly organic material which has fallen from the vegetation above (such as leaves, logs, and twigs). It also includes the remains of animals and insects. Sometimes this organic material is decomposing so that it is difficult to recognize the leaves, twigs, or other material that were originally there. O horizons are most commonly found in forested areas. Agricultural fields, deserts, and grassy areas do not have O horizons in their soil profiles.

A Horizon

The A horizon is given its name because, like the first letter of the alphabet, it is the first mineral horizon of the soil and is commonly known as *topsoil*. The A horizon is made up mostly of mineral matter, although it may also include thoroughly decomposed organic material giving it a dark color. This horizon is usually darker than the horizon below it. In agricultural areas, the A horizon is the one that is tilled. When there has been much root decomposition and organic matter accumulation, the soil structure is granular. If compacted, the structure of the A horizon may be platy.

Figure SOIL-I-2



B Horizon

The B horizon is so named because it is generally the second major horizon in the profile, just as the letter B is the second letter of the alphabet. This horizon is primarily composed of parent material which has been severely weathered to the point that it is different in appearance. This horizon is commonly known as *subsoil*. Weathering causes changes in soil color, texture, and structure (which can be blocky or prismatic because of clay particles and chemical elements that move into the B horizon or columnar because of a high sodium content in dry regions). Also, the B horizon is called the accumulation (or *illuvial*) horizon because it is where the material leached from the A and E horizons has been deposited. Due to this accumulation, the B horizon may be rich in clays, organic matter, iron, aluminum, and other soil constituents that have moved in from above. Many B horizons have a reddish, yellowish brown, or tan color that is lighter than the A horizon. If the soil is saturated with water for long periods of time, the color may be gray or gray with red or orange streaks (mottles) through it.

Note: B Horizons may be very thick and may be broken down into two or more different layers. If there is more than one B horizon, they can be labeled as B1, B2, B3, etc. Look for changes in color, texture, structure, or consistence to help separate the B horizons from each other.

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C Horizon

Like the letter C in the alphabet, the C horizon is usually the third major horizon in a soil profile. The C horizon is the most similar to the original parent material of the soil with no change in color, no structure formed (the soil is massive or single grained), no removal or deposition of soil materials through leaching, no coatings, no organic matter accumulation.

E Horizon

In certain soils (usually forested or under some wet conditions), an E horizon forms. The E horizon was named from the word *eluvial* meaning that clay, iron, aluminum, organic, and other minerals have been removed (leached) from it. It will appear white or lighter in color than the horizons above and below it. Many times, the soil structure is platy or single grained. This horizon is commonly found in forests where coniferous trees grow.

R Horizon

The R horizon represents a layer of rock that is sometimes found under the soil profile. The soil might have formed from this bedrock, or the soil parent material (such as *alluvial*, glacial or volcanic material) may have been deposited on top of the rock before the soil was formed.

Note: In a soil profile, you may not find all the horizons listed above in this table. For example, usually O and E horizons are found only in forested areas. If your soil profile is in an agricultural, desert, or grassy area, it will probably start with an A horizon and not have an E horizon at all. If the area has been eroded, your soil profile may start with a B horizon. Shallow soils, or soils that have not been extensively weathered may go from an A to a C horizon with no B horizon at all.

Your soil may have been altered by human activity at some time in the past. This could be a result of construction, when the builders placed soil *fill* from another location on this site, or when the horizons were not replaced in the same order as they were removed. Also, there may be more than one parent material from which your soil was formed. Parent material transported by water, wind, glaciers, volcanic activity, or landslides can be deposited on top of other parent material, or already existing soil profiles. This may become evident on the face of the soil profile by a sharp change in color, texture or other properties that indicate the soil did not all form from the same parent material.

Soils Around the World

The following figures illustrate a variety of soil profiles from around the world.

Figure SOIL-I-3: Grassland soils sampled in the southern part of Texas in the USA.

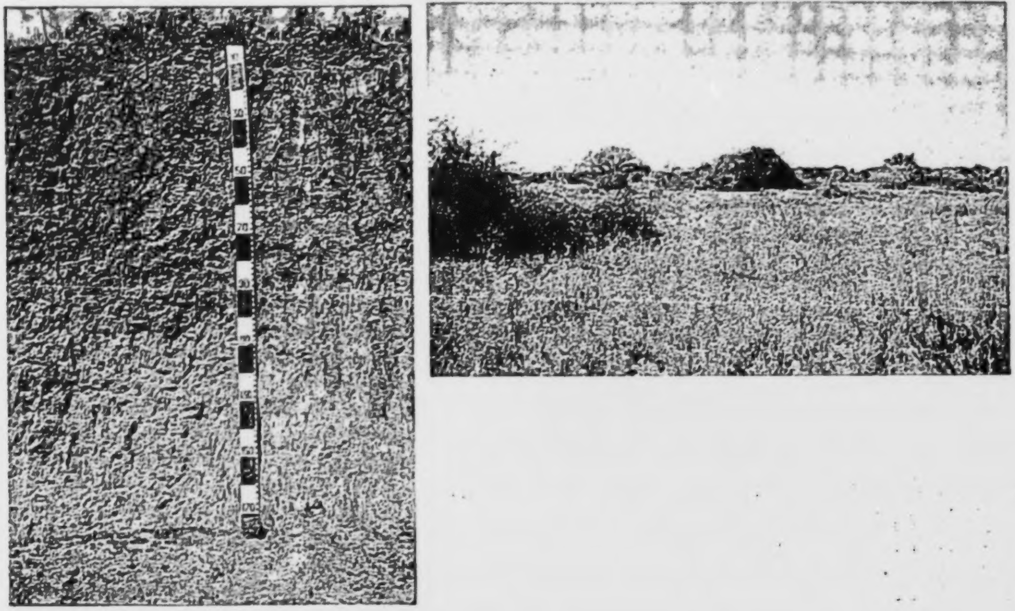


Figure SOIL-I-4: Soil formed under a forest in far eastern Russia, near the city of Magadan.

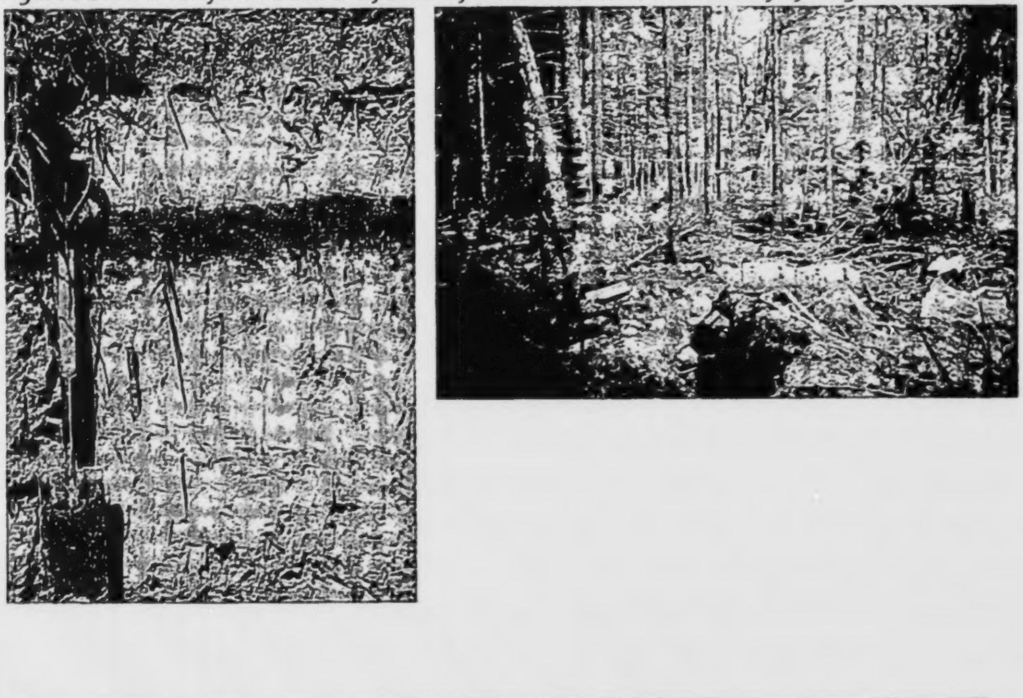


Figure SOIL-I-5: A tropical environment in Northern Queensland, Australia

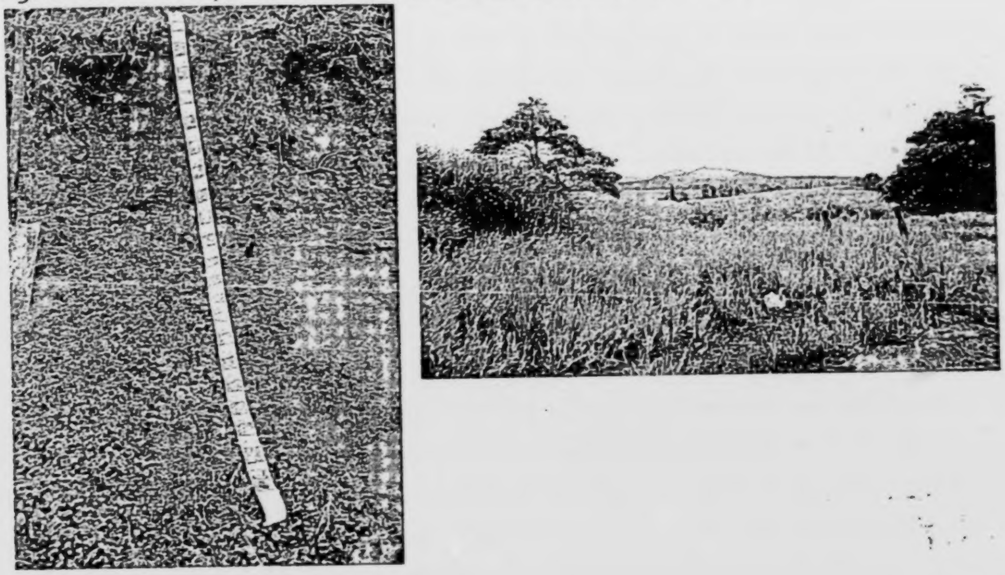


Figure SOIL-I-6: Soil formed under a very cold climate near Inuvik in the Northwest Territory of Canada.

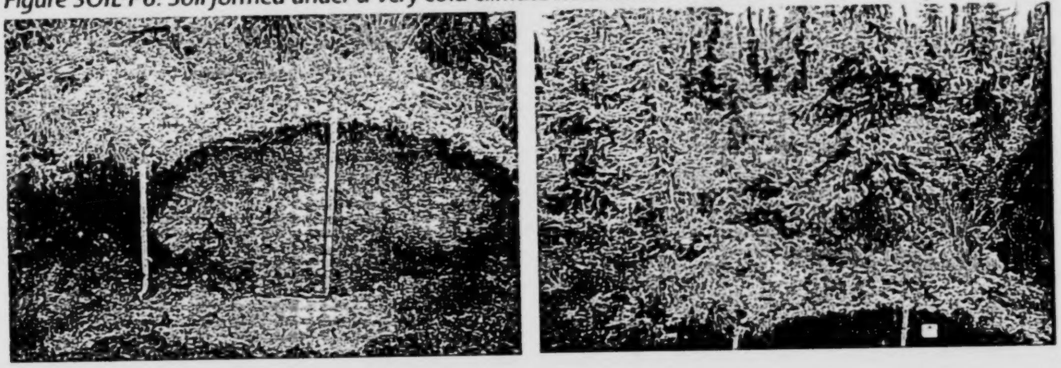


Figure SOIL-I-7: Soil formed under very dry or arid conditions in New Mexico, USA.

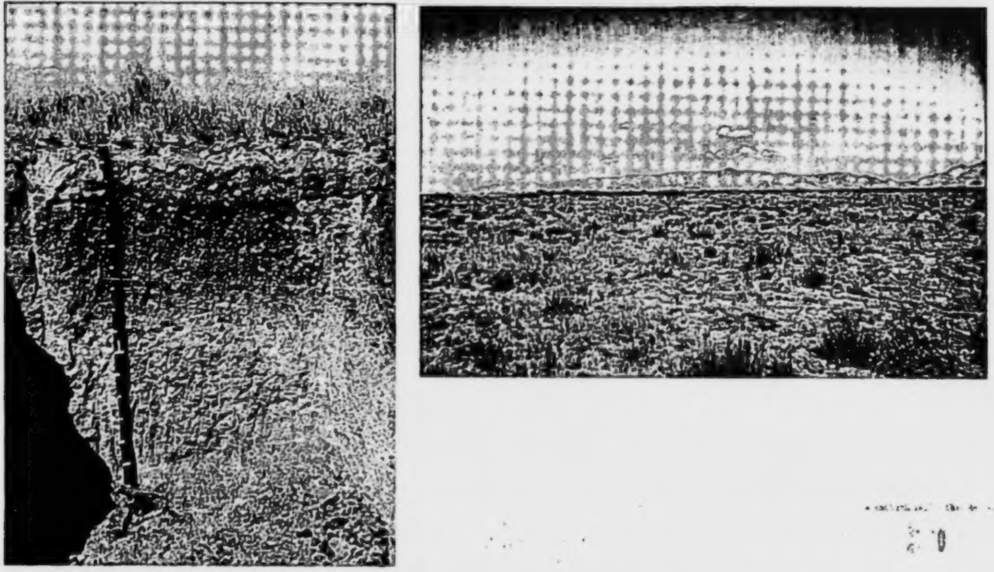
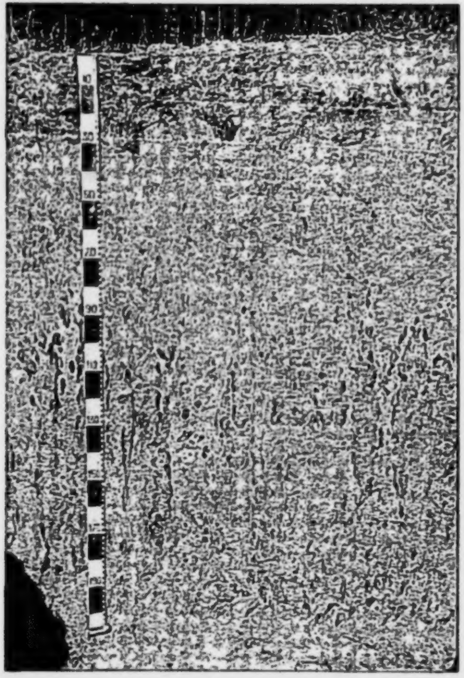


Figure SOIL-I-8: Wet soil sampled in Louisiana, USA



Dr. John Kimble and Sharon Waltman of the USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska provided the photographs shown here.

Overview of the Measurements

Soil Characterization

In the field, soil horizons can be distinguished from each other within a soil profile by differences in their structure, color, consistence, texture, and amount of free carbonates. When samples are taken back to the classroom or laboratory, measurements of soil characteristics such as bulk density, particle size distribution, pH, and soil fertility can also be different from one horizon to another.

Structure:

Structure refers to the natural shape of groups of soil particles or aggregates (*peds*) in the soil. The structure affects how big the spaces will be in the soil through which roots, air, and water may move.

Color:

The color of the soil changes depending on how much organic matter is present and the kinds of minerals it contains (such as iron which usually creates a red color, or calcium carbonate which colors the soil white in dry areas). Soil color also differs depending upon how wet or dry the soil sample is and can indicate if the soil has been saturated with water.

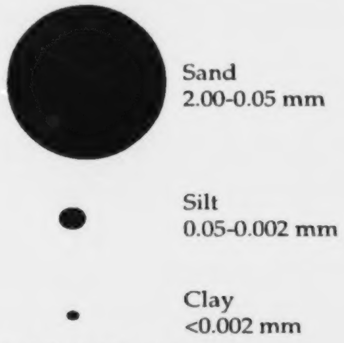
Consistence:

Consistence relates to the firmness of the individual *peds* and how easily they break apart. A soil with firm consistence will be harder for roots, shovels, or plows to move through than a soil with *friable* consistence.

Texture:

The texture is how the soil feels and is determined by the amount of sand, silt, and clay particles in the soil, each of which is a different size.

Human hands are sensitive to this difference in size of soil particles, so we are able to determine the texture or "feel" of the soil. Sand is the largest particle size group, and feels gritty to touch. Silt is the next size group, and feels smooth or *floury*. Clay is the smallest size group, and feels sticky and hard to squeeze. The actual amount of sand, silt, and clay size particles in a soil sample is called the *particle size distribution* and can be measured in the laboratory or classroom.



The relative (not the actual) size of sand, silt, and clay particles.

Figure SOIL-I-9

Carbonates:

Free carbonates are materials that coat soil particles in soils that are above pH 7, especially in arid or semi-arid climates. Carbonates usually have a white color, and can be scratched easily with a fingernail. They are salts of calcium or other elements that accumulate in areas where there is not extensive weathering from water. Also, carbonates can come from the parent material (e.g. limestone), can be caused by additions of carbonates to the soil, or can be the result of carbonate formation within the soil. Sometimes in dry climates, the carbonates can form a very hard and dense horizon which is similar to cement and will not allow plant roots to grow through it.

In GLOBE, this test is performed by squirting vinegar on the soil. If carbonates are present, there will be a chemical reaction between the vinegar, which is an acid, and the carbonates, which are bases, to produce carbon dioxide. When carbon dioxide is produced, it bubbles or *effervesces*. The more carbonates that are present, the more bubbles or *effervescence* you will observe.

Bulk Density:

Soil bulk density is a measurement of how tightly packed or dense the soil is. It is determined by measuring the weight of dry soil in a unit of volume (g/cm^3). How dense the soil sample is depends on the structure (shape) of the soil peds, how many spaces (pores) are in the sample, how tightly they are packed, and also the composition of the solid material. Soils made of minerals (sand, silt, and clay) will have a different bulk density than soils made of organic material. In general the bulk density of soils can range from 0.5 g/cm^3 in soils with many spaces, to as high as 2.0 g/cm^3 or greater in very compact horizons.

Knowing the bulk density of a soil is important for many reasons. Bulk density can give us information about the porosity (the proportion of the soil volume that is pore spaces) of a sample. This helps determine how much air or water can be stored or moved through the soil. Bulk density also indicates how tightly soil particles are packed together and if it will be difficult or easy for roots to grow or shovels to penetrate into and through a soil horizon. Bulk density is also used in converting between weight and volume for a soil sample. If we know the weight of a soil sample, we can calculate its volume by dividing the sample weight by the bulk density of the soil. If we know the volume of a soil sample, we can determine its weight by multiplying the sample volume by the bulk density of the soil.

Particle Size Distribution:

The amount of each particle size group (sand, silt, or clay) in the soil is called the soil particle-size distribution. Knowing the particle size distribution of a soil sample helps us understand many soil properties including how much water, heat, and nutrients the soil will hold, how fast water and heat will move through the soil, and what kind of structure and consistence will form.

The distribution of sand, silt, and clay in your sample will be determined by a settling measurement using an instrument called a *hydrometer*. The hydrometer is used to measure the amount of soil that stays in suspension after some of the soil has settled to the bottom of the cylinder.

Sand is the largest soil particle size group, silt is intermediate in size, and clay is the smallest. See Figure SOIL-I-9. There is disagreement in the scientific community about the exact size ranges used to distinguish sand from silt. For GLOBE, we will be measuring sand and silt based on 2 different size definitions:

1. The US Department of Agriculture (USDA) defines the size of sand as 2.0 - 0.05 mm, and the size of silt as 0.05 - 0.002 mm.
2. The International Soil Science Society (ISSS) defines the size of sand as 2.0 - 0.02 mm, and the size of silt as 0.02 - 0.002 mm.

GLOBE students will find the silt and sand amounts for both of these definitions so that our data can be used by scientists world wide.

Clays are the smallest particle size group and are defined by both organizations as being smaller than 0.002 mm. Particles greater than 2 mm are called stones or gravels and are not considered to be soil material.

Heavy, large particles settle first, so when a soil sample is stirred or shaken in a 500 mL cylinder, sand particles (according to the USDA definition) settle to the bottom of the cylinder after 2 minutes, while the clay and silt size particles stay in suspension. After 12 minutes, the sand (according to the ISSS definition) has settled, leaving the clay and silt particles in suspension. After 24 hours, the silt particles have settled, leaving only the clay in suspension.

pH:

The pH of a soil horizon (how acidic or basic the soil is) can be measured in the laboratory or classroom. The pH influences what can grow in the soil and is the product of the kind of parent material, the chemical nature of the rain and other water entering the soil, land management practices, and the activities of organisms (plants, animals, fungi, protists, and monera) living in the soil. For example, needles from pine trees are high in acids, and as they decay over time, they lower the pH of the soil. Soil pH is an indication of its chemistry and fertility. Just like the pH of water, the pH of soil is on the same logarithmic scale (see the *Introduction* of the *Hydrology Investigation* for a description of pH). It is important to know the pH of the soil because it affects the activity of the chemical elements in the soil, and so affects many soil properties. Different plants grow best at different pH values. Farmers will add *amendments* like calcium carbonate or calcium sulfate to change the pH of the soil depending on the kind of plants they want to grow. The pH of the soil also may affect the pH of ground water or of a nearby water body such as a stream or lake.

Fertility:

The fertility of a soil is determined by how many nutrients it has stored. Nitrogen (N) in the form of nitrate, phosphorus (P), and potassium (K) are three soil nutrients important for the growth of plants, and need to be maintained in the soil at a suitable level. Each also has the potential to leach from the soil into groundwater. By testing the soil for N, P, and K, we can determine how much of each is present in the soil horizons at your sample sites. Soil fertility information can help to explain why and how well certain plants grow at a Soil Characterization Sample Site, and also can be related to the water chemistry you will be measuring in the *Hydrology Investigation*.

Sampling Strategy

The protocols for Soil Characterization should be done once at each site where soil affects another GLOBE measurement. The two highest priority sites are within the Biology Study Site and the Soil Moisture Study Site. The protocols are divided between field and classroom activities. In the field, students describe and sample soil. For this, a hole is dug either with a shovel or an auger. Obtaining a soil profile one meter deep is desired, but an option is provided to sample the top 10 cm of soil when obtaining a 1 m profile is not possible. All students will describe the soil, take samples back to the classroom, dry and sieve the samples, determine the bulk density, and measure them for pH, nitrate, phosphorus, and potassium (N, P, K), and soil particle-size distribution. A measurement of surface infiltration rate should be taken as well.

Soil Moisture

Students should measure soil moisture at least twelve times every year at regular intervals. The choice of whether to take weekly measurements for 12 weeks, monthly measurements throughout the year, or 12 measurements at intervals of two or three weeks is left to GLOBE teachers and students. Different sampling patterns will provide data that are used by scientists in different ways and will show students different aspects of the variations in soil conditions. Measurements will be more interesting to students if they observe significant changes. Generally, soil moisture conditions will change most rapidly in early summer or during the transitions between the wet and dry seasons. Teachers and students should choose a sampling strategy which works well in the context of their school and which will result in 12 measurements being taken.

Any one of three sampling strategies can be chosen to match the capabilities of the students and the situation in your school. Again, different sampling strategies will produce data that will be used in different ways and will illustrate different aspects of soil moisture variation. A simple drying and weighing procedure is used to determine the soil water content of the soil samples in all three strategies.

In the easiest strategy, students sample soils near the surface at 0 - 5 cm, which is as deep as soil-moisture sensors on satellites penetrate the ground, and at 10 cm. Three samples are taken at each depth to provide a good check on data quality for a single location. In a second strategy, students take samples of the soil from a depth of 0 - 5 cm, every 5 m along a 50 m transect. This provides good information on local variations and a better characterization of an extended area. Three samples are taken at one location along the transect to check data quality. With both these sampling strategies, since students and satellites observe soil moisture near the surface, the two sets of measurements can be compared. The GLOBE data can be used to help calibrate, validate, or interpret the data from satellite sensors or aircraft versions of them. In a final strategy, samples are collected at five depths —

0-5, 10, 30, 60, and 90 cm. This strategy provides insight on how water moves through the soil column and provides data that better relate to the uptake of water by plants.

Students collect their soil moisture samples, place them in labeled soil sample containers and weigh them. Then, the samples are dried in a low-temperature oven (75 - 105 C) until all water is removed and the samples are weighed again. The difference in the weights before and after drying equals the amount of water that was in the soil. Scientists call this the *gravimetric* technique, which means a measurement by weight. The ratio of the weight of the water to the weight of the dry soil is called the *soil water content*. Note that this is not a percentage, since you do not divide by the total wet weight. The dry weight is an indication of the size of the soil sample. It is used because bulk density is usually a constant characteristic of a soil. When you divide the weight of the water by the dry soil weight, you get a number (soil water content) which can be compared with your measurements on other days even though the size of the soil samples may vary from one day to the next.

Soil water content typically ranges between 0.05 and 0.40 g/g. Often these values are multiplied by 100, and that is the convention we ask GLOBE students to follow. Even desert soils retain a small amount of water, although surface soils can fall below 0.05 g/g. Organic-rich soils, peat, and some clays can absorb large amounts of water, so it is possible to measure values above 0.40 g/g.

Infiltration

Infiltration, the rate water flows into the ground, is an important hydrologic property of soil. Scientists need this information to predict and model how much precipitation runs off or is stored by the soil. Infiltration rate depends upon many factors: soil structure, soil texture, bulk density, soil water content, and organic matter in the soil. Infiltration rates vary from less than 20 mm/hr for clays and compacted soil to 60 mm/min for loose, dry sand.

Infiltration should be measured at least three times each year at your Soil Moisture Study Site and once at each Soil Characterization Sample Site. A simple device called a double ring infiltrometer, made from two concentric cans of different diameters, will be used. Because infiltration varies with soil moisture, which changes with time, students will make one to nine measurements of infiltration over a 45 minute period. These observations should be taken on days when students are also taking soil moisture samples. Because infiltration rate can change by orders of magnitude due to animal or plant disturbances, students will take measurements of infiltration on a given day at each of three locations within 2 meters of one another.

Soil Temperature

Soil temperature measurements are related to the maximum and minimum daily temperatures measured in the *Atmosphere Investigation*. Students should gain useful insights by comparing the air temperatures with these observations as well as with the surface water temperature and precipitation measurements.

Soil temperature is measured at the Soil Moisture Study Site which should be within 100 m of the Atmosphere Study Site. If your school is not taking soil moisture measurements, take soil temperature measurements within 10 m of the Atmosphere Study Site. Measurements are taken at depths of 5 cm and 10 cm and provide data directly related to the measurement of near-surface soil water content at the site. Soil temperature should be measured weekly throughout the year. In addition, every three months on two consecutive days, students should take measurements at roughly two hour intervals throughout the day to reveal how near surface soil temperature varies with time of day at the study site.

Preparing for the Field

Soil Moisture Sampling Strategies and Site Layout

All Soil Moisture Study Sites should be located in the open, away from buildings, overhanging trees, and roads. The sites should not be irrigated. It is highly desirable that the Soil Moisture and Atmosphere Study Sites be within 100 m of one another so that their data can be interrelated and combined to obtain a more comprehensive picture of the environment near each GLOBE school.

The layouts for the three sampling strategies to be used in soil moisture measurement are summarized in the following sections.

The Star

Students collect soil-moisture samples at two depths close to the surface. Over the 12 different measurement days, the samples will be taken in a star pattern with a two meter diameter.

The Transect

Students collect eleven soil samples along a transect. These measurements are particularly helpful for comparison with satellite imagery. The transect is a straight line 50 meters long across an open area. Students measure soil moisture every five meters along this line. At one location along the transect, three samples are taken within 25 cm of one another to assist in checking data quality.

Depth Profile

Students take soil moisture measurements from samples cored out of the ground at five different depths — 0-5, 10, 30, 60, and 90 cm — using an auger.

An *Optional Gypsum Block Soil Moisture Protocol* for measuring soil water content, that is only recommended for advanced students, is given as well. Gypsum blocks are placed in the soil at four depths — 10, 30, 60, and 90 cm. — and students electronically monitor the moisture in the gypsum by determining how well the blocks conduct electricity. These measurements can be most directly related to the *Atmosphere Investigation* observations as they are taken daily. The gravimetric technique for determining soil moisture is used in conjunction with this optional protocol to calibrate the gypsum block readings.

Integrating with Other GLOBE Investigations

This investigation introduces students to rich connections between the soil and the surrounding land, water, and atmosphere. Placing your data collection stations in close proximity to each other will help you study interactions between the observed parameters. Some interesting comparisons are possible when you:

- locate a Soil Characterization Sample Site at the Land Cover/Biology or Soil Moisture Study Sites or at Quantitative Land Cover Sample Sites;
- do the introductory Hydrology activities along with the soil characterization and soil moisture activities; and
- take the soil moisture measurements near the Atmosphere Study Site.

Time Considerations

Spring and fall are usually the best times to study soil moisture near the surface or in depth profiles because the ground is less likely to be frozen or too dry. The activities should be done when students can observe the greatest contrasts.

The day after a rain is ideal for taking a soil moisture walk to observe ponded water, moisture under ground litter, dry and sunny spots, muddy depressions, and the soil beneath a canopy of trees or shrubs.

Educational Activities

Student Learning Goals

The soil system provides a natural laboratory for integrating many science activities. Students will develop an understanding of soil science, geology, biology, and ecology by studying the origin of their soil profile, the profiles of other soils, and how soils are affected over time by climate, vegetation type, parent material, and land use.

Students will understand the role of heat, water, and chemical constituents during soil formation (pedogenesis) and on the soil within their study site. Activities in these areas will provide a natural background for studying chemistry and physics.

Students will learn about soil moisture and temperature and their importance in local and global hydrologic, carbon, and energy cycles. The challenges of using remote sensing to observe the way soils affect regional and global processes will be introduced. Modeling techniques to predict soil properties and ecosystem parameters will also be included.

Students will develop observational skills by identifying soil properties and learning to identify how the interaction of climate, topography, biology, parent material (geology), and time form different types of soils. They will enhance their field skills in taking measurements properly, handling samples, and taking notes.

Students will become familiar with terminology, nomenclature, and methods that scientists use so that students and scientists can communicate with each other.

In addition, students will learn chemistry, physics, and biology concepts, and use math to visualize and model soil and related water properties and processes. Statistics and graphing will also be important to analyze findings.

Student Assessment

To assess your students' learning over the course of this investigation, we recommend that you evaluate students based on their:

Critical Thinking Skills

- Clear understanding and comprehension of concepts: Challenge their comprehension by presenting them with other possible scientific issues for inquiry. How well do they formulate questions, hypotheses, and methodologies to study their problems? Are their interpretations and conclusions thoughtful? In addition, are they critically reviewing information by challenging statements made by scientists, other students, and the teacher? They should be encouraged to question and ask for statements to be clearly explained. This will help create a real scientific community within the classroom that respects everyone's opinions and concerns.
- Observations and record keeping: Accuracy is essential for validation of research. Student observations should take into consideration issues that can compromise data such as sloppy methodology, inadequate sampling, and imprecise record keeping. However, mistakes are part of science. Students must understand that mistakes must be acknowledged in order to correct them. Even when results do not seem to be accurate, it is important that they are reported. Sometimes, even seeing nothing is an important observation. Making up data is lying and will only grow into a bigger problem later.
- Organization of scientific data: Questions at issue should be presented clearly, and pursuit of research and data must be organized to support these questions. Students must be able to judge what is adequate methodology to use in pursuing answers. Students must be able to interpret data to ensure the soundness of their conclusions.

Communication Skills

The purpose of context-based learning is to introduce students to real life situations. Such an approach stresses the importance of communicating with others. Students should be able to communicate information, both verbal and written, in informal and formal settings. Informal settings of the classroom are used to hone their critical thinking skills and their ability to work cooperatively on common goals. Students should be able to work cooperatively with their peers to improve the quality of their investigations. They should be able (at the intermediate and advanced levels) to develop group assignments and tasks directed at achieving the goals of their investigations. This should be evident through conversation and written materials such as group discussions, GLOBE Science Notebooks, or weekly work reports.

Formal expressions of their knowledge through oral presentations and final reports need to be encouraged. These presentations and reports should inform listeners or readers comprehensively of the study in which the student participated. Students should be able to concisely express this information as scientists do at symposiums and in professional journals. Students also should be familiar, comfortable, and able to use the new scientific terminology they are learning. In this way, they will be better able to understand scientific literature and communicate precisely.

Learning to communicate in both formal and informal manners are not only essential science skills but will enable students to function better in adult life. They must be able to express themselves in a comprehensible manner to both their peers and the community.

To assess your students' learning over the course of this investigation, we recommend that you evaluate students based on their GLOBE Science Notebooks, presentations and reports, organization, understanding of concepts, measurement skill, data analysis and presentation, and soundness of conclusions.

Protocols

Part One: How to Perform Your Soil Characterization

Students will locate a soil characterization sample site and prepare materials for field work.

Soil Characterization Field Measurements Protocol

Students will dig a hole, describe the characteristics of the horizons in the soil profile, and take samples of each horizon for analysis in the lab.

Soil Characterization Lab Analysis Protocol

Students will prepare samples for lab analysis and perform bulk density, particle size distribution, pH, and soil fertility measurements.

Part Two: Soil Moisture and Temperature

Students will locate a soil moisture study site and choose a sampling strategy and measurement frequency.

Gravimetric Soil Moisture Protocol

Students will measure soil water content 12 times per year using one of three sampling strategies.

Optional Gypsum Block Soil Moisture Protocol

Students will install gypsum blocks at four depths, measure their conductivity daily, and develop a calibration curve to permit conversion of the conductivity values to soil water content.

Infiltration Protocol

Students will measure the rate at which water soaks into the ground as a function of time.

Soil Temperature Protocol

Students will measure near-surface soil temperature weekly near local solar noon and seasonally throughout the diurnal year.

Part One:
How to Perform Your Soil Characterization

Sample Sites for the Investigation

Each GLOBE school is expected to perform the Soil Characterization protocols for at least two study sites. These are the Soil Moisture Study Site (see *Part Two: Soil Moisture and Temperature*), and the Biology Study Site (see the *Land Cover/Biology Investigation*). At each location, students dig a hole and examine the soil. Obtaining a soil profile to a depth of at least one meter into the ground is preferred wherever possible. Since the Soil Characterization Protocols are done only once for each location, the sites for which they are performed are referred to in GLOBE as Soil Characterization Sample Sites.

In many places, the soil profiles will vary significantly across the 15 km x 15 km GLOBE Study Site. Characterizing soil profiles at locations other than the two required sites can provide important additional science data and educational opportunities, and you are invited to do them. There is no limit on the number of soil characterizations you may submit to the GLOBE Student Data Server.

Some special opportunities may exist within your GLOBE Study Site to view soil profiles without digging. Road cuts may expose soil profiles; these can be sampled and characterized, but you should obtain a fresh profile face by removing the weathered surface with a shovel before proceeding with your observations and samples. Excavation sites are often interesting and usable. As always, make sure to be safe, and obtain any permissions required.

Locating a Soil Characterization Sample Site

There are several options for exposing and sampling the soil at a Soil Characterization Sample Site:

- Dig a soil pit at least 1 meter deep and as big around as is necessary to easily observe all of the soil horizons from the bottom to the top of the pit,
- Use a road cut, excavation site, or other location where others have exposed at least the top 1 meter of soil,
- Use an auger to remove soil samples to a depth of 1 meter, or
- Use a garden trowel or shovel to sample only the top 10 cm of soil if digging to a depth of 1 meter is not possible.

Some parts of the Soil Characterization Field Measurement Protocol are different depending upon which of these methods you are using.

If you will be digging to expose a soil profile, the Soil Characterization Sample Site should be:

- Safe for digging. Check with local utility companies and maintenance staff to ensure that you do not dig into or disturb a utility cable, water, sewer, or natural gas pipe, or sprinkler irrigation system of some kind,
- Under natural or representative cover. Find a relatively flat location with natural vegetation,
- Relatively undisturbed. Keep at least 3 meters from buildings, roads, paths, playing fields, or other sites where soils may have been compacted or disturbed by construction, and
- Oriented so that the sun will shine on the soil profile to ensure that the soil characteristics are clear for both naked-eye observations and photography.

Preparing for the Field

Bulk Density Containers

If your students have access to a soil drying oven, then they will be able to measure the bulk density of the soil layers. If not, skip this section and continue with the other materials to prepare.

If you are digging a soil pit, doing a near surface measurement or using a soil face exposed by others (road cut, excavation, etc.):

- Obtain 15 soil cans (enough for 5 horizons) or 3 cans if you will only be doing a near surface measurement.
- Label each can.
- Determine the volume of each can by:
    - Filling each can to the top with water (as full as you can).
    - Pouring the water into a graduated cylinder and measure its volume in mL (equal to cubic centimeters).
    - Recording the result on the Bulk Density Data Work Sheet. The volume of water that fills the can is equivalent to the volume of the can.
- Once the volume has been measured, make sure the can is dry and poke a small hole in the bottom of the can with a nail, to allow air in the can to escape when soil is being pressed into the can.
- Weigh each can.
- Record each weight on the Soil Bulk Density Data Work Sheet.
- Provide a lid or other means to seal each can for transport of the samples from the field to the laboratory.

If you are using the auger technique:

- Obtain 15 soil containers (enough for 5 horizons). In choosing containers remember the following:
    - The opening of each container should be large enough so that you can easily transfer a soil sample from the auger to the container without losing any of it.
    - The soil sample will be dried using a soil drying oven, and the best approach is to place the soil directly into the container in which it will be dried.
    - Plastic bags have big openings, but they melt and the soil sample must be transferred to metal, glass, or other containers before drying in the oven. Transferring the soil sample provides an opportunity for some of the sample to be lost.
    - The combined weight of your container and soil sample must not exceed the capacity of your scale or balance.
- Label each container.
- Weigh each container in which the soil will be dried.
- Record each weight on the Soil Bulk Density Data Work Sheet.
- Provide a lid or other means to seal each container for transport of the samples from the field to the laboratory.

Other Materials to Prepare

Fill a small acid bottle with distilled white vinegar to test for free carbonates.

Fill squirt bottles with water (it need not be distilled).

Make a clinometer if you do not already have one. See the *Land Cover/Biology Investigation*.

Soil Characterization Field Measurements Protocol

Purpose

To characterize the soils at the selected sites

To obtain additional site information

To gather samples from each horizon in order to perform later soil tests in the classroom

Overview

This protocol is divided into five tasks. In the first task, students will expose a 1 meter deep soil profile and identify the soil horizons. When this is not possible, a sample 10 cm deep can be taken to use for characterization. In the second task, students characterize the horizons by observing seven properties of soil layers. The students then perform the *Infiltration Protocol*, obtain additional site information, and take soil samples to use in determining bulk density, soil particle size distribution, soil pH, and soil fertility. In the final task, soil samples will be taken to the classroom and the drying of the samples begun.

Time

Preparation of materials - up to one class period

Soil pit including digging – up to one school day

Identifying horizons and taking samples from a soil pit - one or two class periods

Exposing and characterizing the soil profile using an auger and sampling – one or two class periods

Characterizing and taking a soil sample from 10 cm depth – one class period

Level

All

Frequency

Once at each of at least two sites (Soil Moisture Study Site and Biology Study Site).

Three samples of each horizon must be taken in the field for the *Soil Characterization Lab Analysis Protocol*.

Key Concepts

- Soil horizon
- Soil profile
- Color
- Texture
- Structure
- Consistence
- Free carbonates
- Bulk density
- Root distribution
- Soil measurements may be influenced by external factors such as land use, vegetation type, climate, parent material, and topography.
- Sampling procedures

Skills

- *Describing* soil characteristics
- *Using* a clinometer
- *Describing* a landscape
- *Collecting* samples
- *Preparing* samples for lab analysis

Materials and Tools

- Garden trowels
- Shovels
- Dutch or other auger (See *Toolkit* for specifications)
- Water bottle with squirt top (e.g. a well-rinsed dish-washing liquid bottle) or atomizer with a trigger for wetting soil)
- Plastic sheet, tarp, board, or other surface on which to lay out a soil profile removed using the auger
- Soil color book
- Nalgene acid bottle filled with distilled white vinegar

Bulk density sample containers (or other sample containers if your school is not equipped to do bulk density measurements)
Block of wood
Hammer
Meter Stick or tape measure or chop sticks with metric units
20 nails, golf tees, or chop sticks for marking lower and upper boundaries of horizons
Soil Characterization Data Work Sheet
Bulk Density Data Work Sheet
Soil Characterization Information Sheet
Pencils
Water Proof Marker
Clip boards
Small towel for cleaning hands
Plastic bags or sealable containers roughly one-liter in size for transporting soil samples
One roll of tape for sealing the sample bags, cans, or other containers
A box, sack, or bucket for transporting soil samples to the classroom
One waterproof marker for labeling the sample bags
Clinometer for measuring slope (see *Land Cover/Biology Investigation*)
A camera and color film or a digital camera for photographing the soil profile and landscape (slides are acceptable)
GLOBE Science Notebooks

Preparation

Select the site, obtain permission to dig, prepare the bulk density containers, gather the other tools and materials, have the pit dug.

Prerequisites

Preliminary discussion of soil horizons, structure, color, consistence, texture, free carbonates, and bulk density

Preparation

Secure the Soil Characterization Data Work Sheet (one copy is enough for six horizons) on a clipboard.

Take along the Soil Characterization Information Sheet from the *Appendix* to help you take the field measurements, the MUC system pages including definitions (from the *Land Cover/Biology Investigation*), and your GLOBE Science Notebooks.

Assemble all the field measurement equipment:

- Digging equipment as appropriate: auger(s), shovel(s), garden trowel(s)
- Meter stick or tape measure with metric units
- Nails, chopsticks, golf tees, etc.
- Soil color book
- Squirt bottle(s) with water
- Acid bottle filled with distilled white vinegar
- Bulk density sample containers (or other sample containers if your school is not equipped to do bulk density measurements)
- Plastic bags or sealable containers roughly one liter in size for transporting soil samples
- Clinometer
- One roll of tape for sealing the sample bags, cans, or other containers
- A box, sack, or bucket for transporting soil samples to the classroom
- Hand towel(s)
- Pencils
- Waterproof marker(s)
- Camera
- GPS if available

In addition for the auger technique:

- Plastic bag, tarp, board, or other surface on which to lay out the soil profile
- Copies of the Bulk Density Data Work Sheet for the Auger Technique (one copy is needed for each horizon so have at least five copies available)

How to Expose and Identify Soil Horizons

Soil Pit Technique

With this technique, students (or others) expose the soil profile by digging a soil pit.

1. Dig a pit one meter deep and as big around as is necessary to easily observe all of the soil horizons from the bottom to the top of the pit. As soil is removed from the pit, place the soil from each horizon in a separate pile. After the observations have been made and samples taken, the soil should be returned in the opposite order in which it was removed (i.e. the soil taken from the bottom of the pit should go in first, etc.).
2. If you need help to dig the soil pit, call upon parents, other teachers, custodians, student athletes, and local agricultural service personnel.
3. Have students look at the side of the soil pit on which the sun shines most directly so that soil properties will be clearly visible.
4. Starting from the top of the profile and moving down to the bottom, observe the soil profile closely to identify where there are changes in the appearance of the soil face.
5. Look carefully for any distinguishing characteristics like different colors, roots, the size and amount of stones, small light or dark nodules (called *concretions*), worms or other small animals and insects, worm channels, and anything else that is noticeable. If the soil is very dry, wetting it with your squirt bottle may help to distinguish color difference between horizons.
6. Mark the location of each of these changes or boundaries by sticking a nail, golf tee, chop stick, or other marker into the soil face. Sometimes it is difficult to identify differences in horizons because the properties of the whole soil profile are very similar. In this case, there may be only a few very thick horizons present. Do your best to record exactly what you observe in the field.
7. Measure the top and bottom depths for each horizon to the nearest cm and record them on Soil Characterization Data Work Sheet.
8. If horizons are very thin, (<3 cm from top to bottom) do not describe them as separate horizons; combine them with the horizon above or below instead. Thin horizons should be noted in your GLOBE Science Notebooks. Students who wish to do so can identify the horizons by letter name using the descriptions given in the Introduction Section.
9. Proceed to characterize the properties of each of the soil horizons identified. Perform this characterization as soon as possible after the pit is dug.
10. Once this protocol is completed, students should fill in the pit with the original soil. If there are educational or other reasons why the pit is not refilled immediately, take appropriate precautions to ensure that the pit is not a hazard.

Existing Exposed Soil Profiles (a road cut, excavation, etc.)

1. Obtain permission to take samples from the road cut, excavation, or other soil profile exposed by others. Obey any and all safety precautions requested.
2. Expose a fresh soil face by scraping the soil profile with the edge of the garden trowel or other digging tool to remove the surface layer.
3. Perform Steps 4 - 10 as given for the Soil Pit Technique.

Auger Technique

With this technique, students display the vertical soil profile on a horizontal surface (the ground). Be sure to use the correct auger for your site. A Dutch auger, as described in the *Toolkit* is best for most soil, especially for rocky, clayey, and dense soils. A sand auger is needed if your soil is very sandy in texture. In some places, the soil is mostly peat and a special peat auger should be used. A bucket auger may be better for dry, desert soils.

1. Identify an area where you can dig four auger holes where the soil profiles should be similar.
2. Spread a plastic sheet, tarp, board, or other surface on the ground next to where you will dig your first hole.
3. Assemble a profile of the top 1 meter of the soil by removing successive samples from the ground with the auger and laying them end-to-end as follows:
   3.1. Turn the auger one complete revolution (360°) to dig into the ground.
   3.2. Remove the auger with the sample in it from the hole.
   3.3. Hold the auger over the plastic sheet, tarp, or board.
   3.4. Transfer the sample from the auger to the plastic sheet, tarp, or board as gently as possible. Place the top of this sample just below the bottom of the previous sample.
   3.5. Measure the depth of the hole. Adjust the sample on the plastic bag, tarp, or board so that its bottom is no further from the top of the soil profile than this depth.
4. Starting from the top and moving down to the bottom, observe the soil profile closely to identify where there are changes in the appearance of the soil.
5. Look carefully for any distinguishing characteristics like different colors, roots, the size and number of stones, small light or dark nodules (called *concretions*), worms or other small animals and insects, worm channels, and anything else that is noticeable.
6. Mark the location of each of these changes or boundaries by sticking a nail, golf tee, chop stick, or other marker into the soil profile you have constructed. Sometimes it is difficult to identify differences in horizons because the properties of the whole soil profile are very similar. In this case, there may be only a few very thick horizons present. Do your best to record exactly what you observe in the field.
7. Measure the top and bottom depths for each horizon to the nearest cm and record them on Soil Characterization Data Work Sheet(s).
8. If horizons are very thin, (<3 cm from top to bottom) do not describe them as separate horizons, but combine them with the horizon above or below instead. Thin horizons should be noted in your GLOBE Student Data Notebook. Students who wish to do so can identify the horizons by letter name using the descriptions given in the *Introduction* section.
9. Proceed to characterize the properties of each of the soil horizons identified. Perform this characterization as soon as possible after the hole is augered.
10. Once these tasks are completed, where ever possible, students should fill in the hole with the original soil.

Near Surface Sample Technique

1. In situations where it is not possible for you to expose the top meter of soil, an additional option is to use the top 10 cm of the soil as a single horizon sample for soil characterization.
2. Use a garden trowel or shovel to carefully remove the top 10 cm of the soil from a small area and set it on the ground.
3. Treat this sample as a horizon and proceed to characterize its properties.

How to Observe and Record Soil Properties

For each horizon identified, the following characteristics should be observed, recorded on the Soil Characterization Data Work Sheet, and reported to the GLOBE Student Data Server using the Soil Characterization Data Entry Sheet. **Note:** The soil characteristics should be observed in the order given.

1. Soil Structure

Take a sample of undisturbed soil in your hand (either from the pit or from the shovel or auger). Look closely at the soil in your hand and examine its structure. Soil structure is the shape that the soil takes based on its physical and chemical properties. Each individual unit of natural soil structure or aggregation is called a *ped*. Possible choices of soil structure are granular, blocky, platy, columnar, and prismatic, and are shown in Figures SOIL-P-1 to 5.

Sometimes your soil may be structureless, which means that within a horizon, soil peds have no specific shape. In this case, the soil structure is either single grained or massive. Single grained is like sand at a beach or in a playground where there are individual sand particles that do not stick together. Massive is when the soil sticks together in a large mass that does not break in any pattern. These conditions are more commonly found in C horizons, the horizons in which the parent material is least altered. Since the parent material has not yet undergone any weathering, it usually has not developed any structure.

It is common to see more than one type of structure in a soil sample. Students should record on their data sheets only the structure type that is most common in their sample. They should discuss and agree upon the structure types they see. If the sample is structureless, record whether it is single-grained or massive.

2. Soil Color

Take a ped from the horizon and note on the data sheet whether it is moist, dry, or wet. If it is dry, moisten it slightly with water from your water bottle. Break the ped and hold the color chart

Figure SOIL-P-1: Blocky Structure

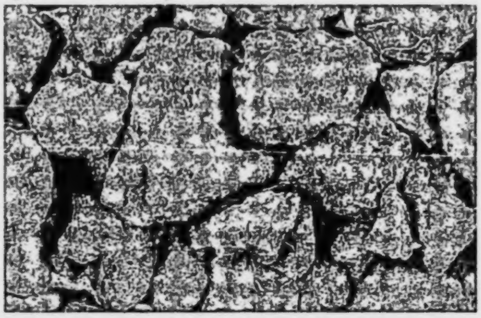


Figure SOIL-P-2: Columnar Structure

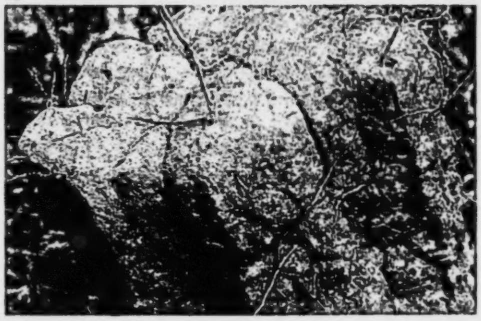


Figure SOIL-P-3: Granular Structure

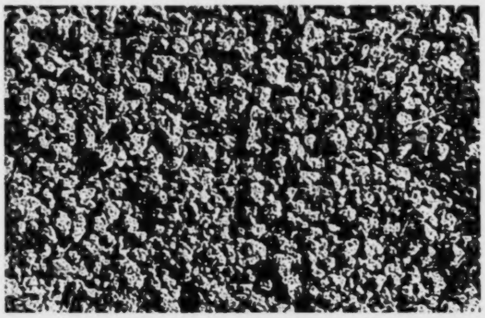


Figure SOIL-P-4: Platy Structure

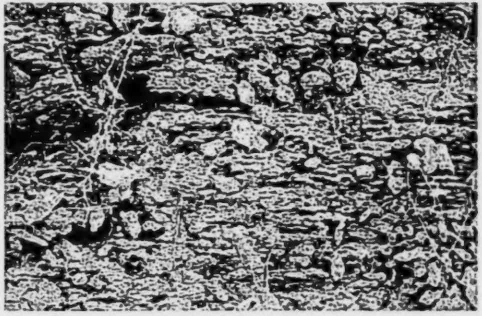
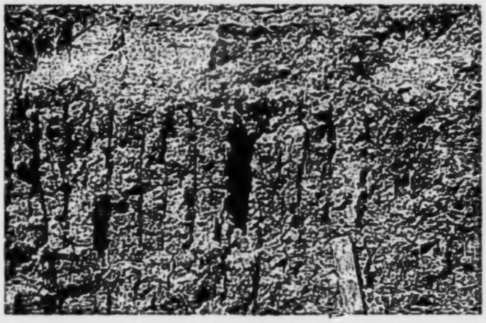


Figure SOIL-P-5: Prismatic Structure



next to it. Find the color from the color chart which most closely matches the color of the inside surface of the ped. Stand with the sun over your shoulder so that sunlight shines on the color chart and the soil sample you are examining. Record on the data work sheet the symbol of the color on the chart that most closely matches the soil's color.

Sometimes, a soil sample may have more than one color. Record a maximum of two colors if necessary, and indicate (1) the dominant (main) color, and (2) the sub-dominant (other) color. Again, students both inside and outside the pit should agree on the choice of color.

3. Soil Consistence

Take a ped from the soil horizon. Record on the data work sheet whether the ped is moist, wet or dry. If the soil is very dry, moisten the face of the profile by squirting water on it, and then remove a ped for determining consistence. Holding the ped between your thumb and forefinger, gently squeeze it until it pops or falls apart. Record one of the following categories of soil ped consistence on the data sheet.

> Loose: You have trouble picking out a single ped and the structure falls apart before you handle it.
> Friable: The ped breaks with a small amount of pressure.
> Firm: The ped breaks when you apply a good amount of pressure and the ped dents your fingers before it breaks.
> Extremely Firm: The ped can't be crushed with your fingers (you need a hammer!)

4. Soil Texture

The texture of a soil refers to the amount of sand, silt, and clay in a soil sample, and the composition of these determines the way the soil feels when you rub it between your fingers. The texture differs depending on the amount of sand, silt, and clay in the soil sample. Sand particles are the largest with sizes up to 2 mm while clay particles are smaller than .002 mm. Particles greater than 2 mm are called stones or gravels and are not considered to be soil material. Even though they are small, the differences among sand, silt, and clay particles can be felt, and each has its own characteristics. Sand feels gritty, silt feels smooth, and clay feels sticky. Usually a combination of these different size particles is found in a soil sample. Soil scientists use charts called textural triangles to help determine what percent of sand, silt, and clay are in a soil. Using Textural Triangles 1 and 2 to help you, follow these steps to identify your soil's texture.

> 4.1. Take a sample of soil about the size of a small egg and add enough water to moisten it. Work it between your fingers until it is the same moisture throughout. Then, squeeze it between your thumb and forefinger in a snapping motion to try to form a ribbon of soil.

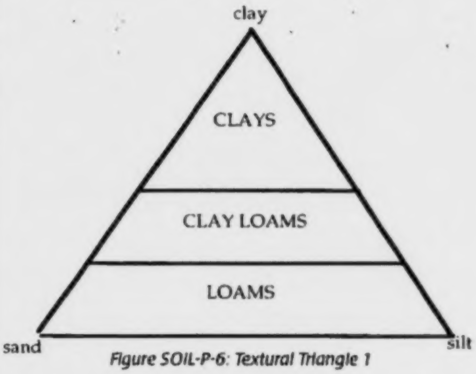


Figure SOIL-P-6: Textural Triangle 1

> 4.2. If the soil feels extremely sticky (sticks to your hands and is hard to work), stiff and requires a lot of thumb and finger pressure to form a ribbon, it is likely composed of mostly clay size particles. Classify it as a clay, as shown on Textural Triangle 1.
> 4.3 If the soil feels sticky and a little softer to squeeze, it probably has fewer clay particles. Classify it as a clay loam.
> 4.4 If the soil is soft, smooth, and easy to squeeze, and is at most slightly sticky, classify it as a loam.

Once the soil has been classified as clay, clay loam, or loam, refine the classification by determining the relative amounts of sand and silt.

> 4.5 If the soil feels very smooth, with no sandy grittiness, add the word "silt" or

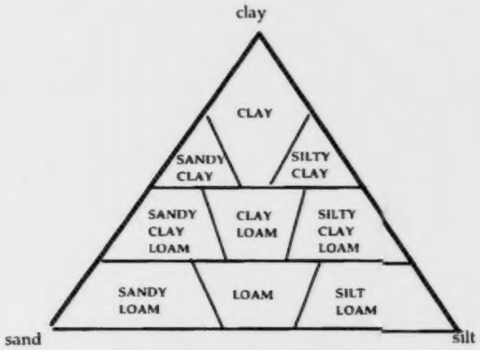


Figure SOIL-P-7: Textural Triangle 2

"silty" to your classification, such as "silty clay", or "silty loam", as shown on Textural Triangle 2. This means that your soil sample has more silt-size particles than sand-size particles.

4.6 If the soil feels very gritty, add the term "sandy" to your soil classification, such as "sandy clay". This means your soil sample has more sand size particles than silt size particles.

4.7 If the soil feels neither very gritty nor very smooth, even if you can feel some sand in your sample, keep your original classification unchanged. This means your soil sample has about the same amounts of sand and silt size particles, and in the case of a clay, it may have very few of either.

Note: When feeling the soil texture, try to add the same amount of water to each sample so that you can more accurately compare one texture to the other. The soil texture can feel differently depending on how wet or dry it is. The amount of organic matter in the soil can also change how it feels. Generally, the darker the soil color is, the more organic matter is in it.

4.8 Record on the data work sheet the name of the soil texture that the students agree on. Also, note whether the sample was dry, wet, or moist when it was examined, and whether it contained a lot of organic matter (for instance if it was on the surface and had a very dark color).

5. Presence of Roots

Observe and record if there are none, few, or many roots in the horizon.

6. Presence of Rocks

Observe and record if there are none, few, or many rocks or rock fragments in the horizon. A rock or rock fragment is defined as being larger than 2 mm in size.

7. Test for Free Carbonates

Perform this test by squirting vinegar on the soil. If carbonates are present, there will be a chemical reaction between the vinegar, and the carbonates to produce carbon dioxide. When carbon dioxide is produced, it bubbles or *effervesces*. The more carbonates that are present, the more bubbles (*effervescence*) you will observe.

7.1. Look carefully at your soil profile for white coatings on the soil and rocks which might indicate that free carbonates are present.

7.2. Set aside a portion of the pit, exposed soil face, or sample from the auger hole or near surface which you do not touch with your hands, and use it for the free carbonates test.

7.3. After you have finished characterizing the other soil properties, test for free carbonates. Open the acid bottle and starting from the bottom of the profile and moving up, squirt vinegar on the soil particles. Look carefully for the presence of effervescence.

7.4 Record one of the following as the results of the Free Carbonate Test for each horizon:

None: if you observe no reaction, the soil has no free carbonates present.

Slight: if you observe a very slight bubbling action; this indicates the presence of some carbonates.

Strong: if there is a strong reaction (many, large bubbles) this indicates that many carbonates are present.

7.5. Do not bring samples contaminated with the vinegar back to the classroom.

Obtain Additional Site Information

At the same time that students take their soil characterization measurements in the field, or within a few months thereafter, spend some time with your class describing and recording details about your site.

1. Measure and record the GPS coordinates of your site.
2. Perform the *Infiltration Protocol* for three places near your soil pit, auger hole, or surface sample, or above the road cut or other excavation. You do not need to measure infiltration on more than one day; the day you are collecting the other soil characterization data is usually a good day to take this measurement.
3. Photograph the soil profile that has been described. Do this on the day measurements are taken in the field.

   If students have exposed the soil profile by digging a soil pit or have used an existing exposed soil profile, place a tape measure or meter stick along the profile with the 0 cm mark at the ground surface. Photograph the profile face from outside the pit, preferably with the sun behind the photographer shining on the exposed profile.

   If the soil profile was obtained with an auger, photograph the soil profile lying on the paper or board on the ground with a tape measure or meter stick lying next to it. Again, have the 0 cm mark at the top or ground surface level of the profile, and have the sun behind the photographer.

   In either case, take another photograph of the landscape around the Soil Characterization Sample Site.

   Send copies of these photographs to the GLOBE Student Data Archive at the address given in the Implementation Guide, or if they were taken with a digital camera, submit them to the GLOBE Student Data Archive electronically.
4. Measure the slope of the sample site using the clinometer from the *Land Cover/Biology Investigation*, and record the slope measurement on the Soil Characterization Data Work Sheet.

   4.1 Designate two students whose eyes are at about the same height to measure the slope.

   4.2 Measure the steepest slope that crosses the hole.

   4.3 The student that holds the clinometer stands down slope and the other walks to the opposite side of the hole.

   4.4 Looking through the clinometer, one student sites the eye level of the other student.

   4.5 Read the angle of slope in degrees and record this reading on the data work sheet.
5. Measure and record the distance from major features (such as buildings, power poles, roads, etc.).
6. Record any other distinguishing characteristics that make this site unique. (While all of the following data will not be reported to GLOBE at the current time, such data should be recorded in the school's local database.)

   Questions you might ask are:

- What are the types of plants and animals you find in the soil and the general area around your site? Include small organisms in the soil such as earthworms or ants.
- What is the parent material from which the soil was formed? Was it bedrock? If so, look for rocks on the surface to tell you something about the kind of rock. Could your soil have been deposited by water or wind, by a glacier or volcano? If necessary, further investigate the surface geology of your area in your local library.
- Where in the landscape is your soil? Is it on a hilltop, slope, or bottom of a hill? Is it next to a stream or on a flat plain? On what kind of land form is it found?
- What is the general climate at your soil site? Is it sunny, shaded, hot, cold, moist, dry?
- What is the recent land use in this area? Has it been stable for a long time, or has it been plowed, its trees cut, used for

construction, or undergone some other disturbance recently?

7. Record all requested information on the Soil Characterization Data Work Sheet.

Information about your site and data collection techniques (often called metadata) should be entered permanently in your GLOBE Science Notebook and registered with your site using the Soil Characterization Sample Site Data Entry Sheet. You are not required to enter all this information, but it is of great help to scientists and others who want to use these data. A sample site must be defined before the soil characterization data for it can be entered. Initially, this definition can consist of no more than a name for the site and the date on which the field observations were made and the soil samples taken. As more information becomes available to characterize the sample site, these data can be added to the GLOBE Student Data Archive using the modify a sample site procedure.

Soil Sampling

The methods for obtaining soil samples for further analysis are different depending on how you have exposed your soil profile.

Soil Pit Technique and Existing Exposed Soil Profiles

Taking Bulk Density Samples

1. For each horizon in your soil profile, push a can with a known volume into the side of the horizon. The soil in the profile should be moist, so that it will stick together and so that the can will go in easily. If necessary, wet the soil before doing this measurement.
2. If it is still difficult to push the can into the soil, you may need to use a hammer or other object to force it in. If this is necessary, place a piece of wood over the can and hit the wood with the hammer to spread the force of the hammer blow to all edges of the can at once and to minimize denting the can.

   Note: Some denting is allowed in this procedure as long as the volume of the can is not changed by more than a few percent, but if the can dents too badly, the soil may be too hard or rocky to take a bulk density sample this way. You might consider taking a bulk density sample using the auger method described below, instead, for the dense horizons.
3. Stop when you can see some of the soil poking through the small hole in the bottom of the can, the can has been filled with soil.
4. Using a trowel or shovel, remove the can and the soil surrounding it. Trim the soil from around the can until it is flat against the edges of the can so that the volume of the soil is the same as the volume of the can.
5. Cover the can with the lid or other cover and return it to the classroom.
6. Repeat this procedure so that you have 3 bulk density samples for each horizon.
7. Label the cans in the field with the site name, horizon number (or letter), top and bottom depths, and sample number (1, 2 or 3 for each horizon).
8. Bring these samples in from the field as soon as possible.
9. Remove the covers.
10. Weigh each sample in its can and record this moist weight on the Bulk Density Data Work Sheet.
11. Place the samples in the soil drying oven.

If you are not measuring bulk density:

1. Dig an ample sample from each soil horizon. Avoid the area of the soil face which was tested for carbonates and avoid touching the soil samples so that your pH measurements will not be contaminated.
2. Place each sample in a bag or other soil container.
3. Label each bag with the site name, horizon number (or letter), and top and bottom depths.
4. Bring these samples in from the field.
5. Spread the samples on separate plastic plates or sheets of newspaper to dry in the air.

Auger Technique

Three samples are needed from each horizon. Each will be obtained from a new auger hole.

Taking Bulk Density Samples:

For each auger hole:

1. Auger to a depth 1 or 2 cm past the top of the horizon to be sampled.
2. Measure the depth of the hole.
3. Use the auger to remove a sample of the horizon. If the horizon has a smaller vertical extent than the length of the auger head, only perform a partial turn of the auger so that the whole sample will be from just this horizon. Do not turn the auger more than one complete circle (360°) so that the soil does not become compacted.
4. Once the sample is removed, transfer all the soil from the auger head to a sample container without losing any on the ground. Avoid handling the sample as much as possible to minimize the soil contamination by natural oils from your skin.
5. Measure the diameter of the hole that the auger made, and the depth of the hole.
6. Label the outside of the container with the horizon name, the diameter of the hole and depth of the hole before and after this sample was removed. (These measurements will be used to calculate the volume of the sample.)
7. Repeat steps 1 - 6 for each horizon in the soil profile.
8. Repeat this procedure in different holes, next to each other, so that you obtain 3 samples of each horizon.
9. Cover or seal the samples and transport them to the classroom.
10. Bring these samples in from the field as soon as possible.
11. Remove the covers.
12. Weight each sample in its container and record this moist weight on the Bulk Density Data Work Sheet.
13. Place the samples in the soil drying oven.

If you are not measuring bulk density:

For each auger hole:

1. Auger to a depth 1 or 2 cm past the top of the horizon to be sampled.
2. Use the auger to remove a sample of the horizon. If the horizon has a smaller vertical extent than the length of the auger head, only perform a partial turn of the auger so that the whole sample will be from just this horizon.
3. Place the sample in a bag or other soil container. Avoid contaminating the sample by touching it with your hands.
4. Label each bag with the site name, horizon name, and top and bottom depths of the horizon.
5. Repeat Steps 1 - 4 for each horizon.
6. Bring these samples in from the field. Spread the samples on separate plastic plates or sheets of newspaper to dry in the air.

Near Surface Sample Technique

Taking Bulk Density Samples:

1. Choose 3 locations close to the location where you performed your *Soil Characterization Protocol*.
2. Remove vegetation and other material from the soil surface.
3. For each of the 3 locations:

   3.1. Push a can with a known volume into the surface of the soil. The soil in the profile should be moist, so the soil will stick together, and the can will press into the ground easily. If necessary, wet the soil before doing this measurement. Let the moisture seep into the soil before sampling. It is preferable to sample moist soils and not wet soils unless the soil is naturally saturated with water.

   3.2. Stop when you can see some soil poking through the small hole in the bottom of the can, you have filled the can.

   3.3. If it is difficult to push the can into the soil, you may need to use a hammer or other object to force it in. If this is necessary, place a piece of wood over the can and hit the wood with the hammer to spread the force of the hammer blow to all edges of the can at once and to avoid denting the can.

  3.4. Slide a trowel or shovel under the can and the soil surrounding it and lift it out carefully. Trim the soil from around the can until it is flat against the edges of the can so that the volume of the soil is the same as the volume of the can.

  3.5. Cover the can with the lid or seal it for transport back to the classroom.

  3.6. Label the cans in the field with the site location and the number of the sample (i.e. 1, 2 or 3).

4. Bring these samples in from the field as soon as possible.
5. Remove the covers.
6. Weigh each sample in its can and record this moist weight on the Bulk Density Data Work Sheet.
7. Place the samples in the soil drying oven.

If you are not measuring bulk density:

1. Dig an ample sample from the top 10 cm of the soil. Avoid the area which was tested for carbonates, and avoid touching the soil samples so that your pH measurements will not be contaminated.
2. Place each sample in a bag or other soil container.
3. Label each bag with the site name, horizon name, and top and bottom depths.
4. Bring these samples in from the field.
5. Spread the samples on separate plastic plates or sheets of newspaper to dry in the air.

Soil Characterization Lab Analysis Protocol

Purpose

To determine the bulk density of the soil

To determine the soil particle size distribution

To measure soil pH

To determine soil fertility by measuring the amounts of nitrate nitrogen, phosphorus, and potassium (N, P, K) in the soil

Overview

In the classroom/laboratory, students will dry the bulk density samples in an oven, weigh them, sieve them to remove rocks, and determine the weight and volume of the rocks. The sieved bulk density or other samples will be used to determine the particle size distribution, the soil pH, and the soil fertility (N, P, K).

Time

For drying soil samples, allow at least 10 hours for drying at 95 - 105 ° C, 24 hours for drying at 75 - 95 ° C, or two days for air drying (no classroom time is involved).

Preparation of dispersing solution needed prior to class - 10 minutes

Dispersing step for Particle Size Distribution procedure, sieving dry samples and completing the bulk density measurement - one class period

2 and 12 minute measurements for Particle Size Distribution, and measurements of Soil pH and Soil Fertility - one class period

Final Particle Size Distribution measurement, clean up, and review of all the data - one class period

Level

Soil Fertility (N, P, K) — Intermediate and Advanced.

Other measurements — All

Frequency

Once for each horizon

Three samples for each horizon

Key Concepts

- Volume
- Density
- Bulk density
- pH of soil
- Soil fertility (N, P, K)
- Soil nutrients
- Chemical reactions
- Specific gravity
- Particle size distribution
- Texture
- Supernatant

Skills

- *Handling* samples
- *Sieving* samples
- *Recording* data
- *Manipulating* scientific equipment
- *Observing* color
- *Pipetting*
- *Measuring* pH, specific gravity, and soil fertility
- *Determining* relative nutrient content
- *Using* a hydrometer

Materials and Tools

For Recording Data During All Measurements:
- Bulk Density Data Work Sheet
- Particle Size Distribution Data Work Sheet
- pH Data Work Sheet
- Soil Fertility Data Work Sheet

For Drying and Sieving Samples:
- Newspapers or plastic plates
- #10 sieve (2 mm mesh openings)

Liter-size bags, jars, or containers for storing soil samples
Balance
Rubber gloves

For Bulk Density
Drying oven or microwave
100 mL graduated cylinder to determine volume of rocks
Balance

For Particle Size Distribution:
Rolling Pin, hammer, or other utensil for crushing peds and separating particles
500 mL clear plastic graduated cylinder
Hydrometer
Thermometer (needs to have a smooth surface without a cover so that soil and water do not got trapped)
Spoon or other utensil to transfer soil
Spoon or stirring rod for stirring soil
Dispersing solution (50 g Sodium Hexametaphosphate/liter or non-sudsing powdered detergent containing sodium and phosphate)
250 mL or larger beaker
Squirt bottle for washing soil out of beaker
Stop watch or a clock with a second hand
Plastic Wrap or other material to cover top of cylinder during shaking
1 L bottle for dispersing solution

For pH:
Three 100 mL-beakers
Balance
pH paper, pen, or meter
Glass stirrer or spoon
Distilled water
100 mL-graduated cylinder to measure distilled water

For Soil Fertility:
Distilled water
Soil Fertility Kit with reagents to measure N, P, and K
Teaspoon
Cup or test tube rack to hold tubes

For Disposing of Soil:
Buckets or other large water tight containers

Preparation

Calibration of pH meter or pen

Prerequisites

Soil Characterization Field Measurement

How to Measure Bulk Density and Prepare Samples for Other Lab Analyses

Bulk Density

1. Dry the samples in their containers following the directions given for drying samples in the *Gravimetric Soil Moisture Protocol*.
2. Weigh each dry bulk density sample in its container and record this dry weight on the Bulk Density Data Work Sheet.
3. Rocks don't hold water or store nutrients, so they don't contribute to the bulk density of soil.

To determine the density of any rocks that are in a sample use the following procedure (if there are no rocks in your sample, skip this part):

3.1 Place a large piece of paper (such as newspaper) on a table and put the #10 (2 mm openings) sieve on top of it. Pour one sample into the sieve.

3.2 Put on rubber gloves to avoid contaminating your sample with acids from your skin.

3.3 Carefully push the dried soil material through the mesh onto the paper. Do not force the soil through the sieve as this may bend the mesh openings. Rocks will not pass through the mesh and will stay on top of the sieve. If no sieve is available, carefully remove the rocks by hand.

3.4 Save the sieved soil from each sample for the other lab analyses.

3.5 Weigh the rocks, and record this weight on the Bulk Density Data Work Sheet.

3.6 Place 30 mL of water in a 100 mL graduated cylinder, and without spilling, add the rocks to the water. Read the level of the water after all the rocks have been added and record this value and the original volume of water on the Bulk Density Data Work Sheet.

As you add the rocks, if the volume of the water comes close to 100 mL, record the increase in volume, empty the cylinder and repeat the procedure for the remaining rocks. In this case, you must calculate and record the sum of the water volumes with the rocks and the sum of the water volumes without the rocks.

Making Sense of the Data

When you are done, the following should have been recorded on your Bulk Density Data Work Sheet and reported to the GLOBE Student Data Server using the Bulk Density Data Entry Sheet:

- the volume of the soil can (mL) (For the pit or surface sampling method)
- the weight of the soil can (g) (For the pit or surface sampling method)
- the diameter of the hole (cm) (For the auger method)
- the top and bottom depth of the hole (cm) (for the auger method)
- the weight of the container (g) (for the auger method)
- the weight of the moist soil and container (g) (only needed if you wish to calculate soil water content)
- the weight of the dry soil and container (g)
- the weight of the rocks (g)
- the volume (or sum of the volumes) of the water added to the graduated cylinder before rocks are added (mL)
- the volume (or sum of the volumes) of the water after rocks have been added (mL)

To calculate soil water content:

In doing the bulk density measurements, if you measured the weight of the moist soil and container you have obtained all the information needed to determine the soil water content of your sample. If you wish to know the soil water content, follow the procedures for this calculation given in the *Gravimetric Soil Moisture Protocol*. These soil water content values are not reported to GLOBE; they are only for student practice and added insight.

If you are not measuring bulk density

Prepare the samples for the lab analyses.

1. Place a large piece of paper (such as newspaper) on a table.
2. Put the #10 (2 mm openings) sieve on top of it.

The bulk density of the soil material (in units of g/cm^3) can now be calculated for each sample by:

$$\text{Bulk density} = \frac{\text{dry weight} - \text{container weight} - \text{weight of rocks}}{\text{container or hole volume} - \text{volume of rocks}}$$

$$\text{Hole volume} = \pi \times \left[\frac{\text{hole diameter}}{2}\right]^2 \times [\text{bottom depth of hole} - \text{top depth of hole}]$$

Volume of rocks = volume of water and rocks – volume of water before rocks were added

If you had to measure the volume of rocks in more than one batch, add the volumes calculated for each batch to get the total volume of rocks.

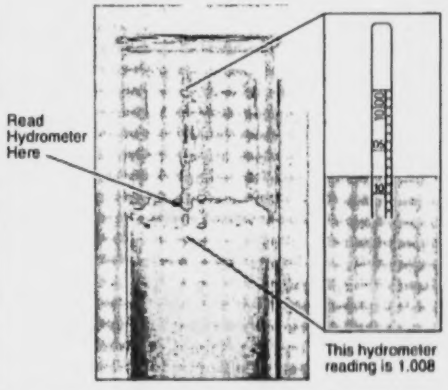
3. Pour the sample into the #10 sieve. Put on rubber gloves so the acids in your skin don't contaminate the soil pH measurement.
4. Carefully push the dried soil material through the mesh onto the paper. Do not force the soil through the sieve or you may bend the wire mesh openings. Rocks will not pass through the mesh and will stay on top of the sieve. Remove the rocks (and other pieces of debris) from the sieve and discard. If no sieve is available, carefully remove the rocks and debris by hand.
5. Transfer the rock-free, dry soil from the paper under the sieve into new, clean, dry plastic bags or containers.
6. Seal the containers, and label them the same way that they were labeled in the field (horizon name, top and bottom horizon depth, date, site name, site location). This is the soil that will be used for the other lab analyses.
7. Store these samples in a safe, dry place until they are used.

How to Measure Soil Particle Size Distribution

Repeat this measurement three times for each horizon, and record all sets of data on the Particle-Size Distribution Data Work Sheet.

1. Prepare the dispersing solution by mixing 50 g of Sodium Hexametaphosphate (or other material as indicated above), in 1 L of distilled water. Dissolve all of the solid material by stirring the mixture.
2. After drying and sieving the soil samples, use a rolling pin, mortar and pestle, or hammer to break up any large particles that might still be present.
3. Weigh 25 grams of dried, sieved soil and pour it into a 250 mL or larger beaker. Pour 100 mL of the dispersing solution and about 50 mL of distilled water into the beaker. Stir vigorously with a spoon or stirring rod for at least one minute. Be sure the soil is thoroughly mixed and does not stick to the bottom of the beaker. Do not spill any of the soil suspension.
4. When the soil and dispersing solution are thoroughly mixed, rinse any soil left on the stirrer into the beaker with the rest of the mixture. Set the beaker aside in a safe place and allow it to sit for about 24 hours (the sample can be left to mix with the dispersing solution over the weekend as well).
5. While the suspension is sitting, put a meter stick or other ruler in the cylinder and measure the distance between the 500 mL mark and the bottom of the cylinder. Also read the temperature at which your hydrometer has been calibrated (such as 15.6° C or 20° C). This number will be found somewhere on the hydrometer. Record both on the Particle Size Distribution Data Work Sheet.
6. After roughly 24 hours (or during the same class period the next school day), stir the suspension in the beaker again, and pour it into a 500 mL graduated cylinder.
7. Using a squirt bottle, rinse out the beaker with distilled water, and add this to the soil mixture in the cylinder.
8. Add enough distilled water to fill the cylinder to the 500 mL mark.
9. Securely cover the top of the cylinder using plastic wrap or another secure cover.

Figure SOIL-P-8



Note: The increased volume level (apparently greater than 500 ml) is caused by the displacement of water by the hydrometer.

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10. Mix vigorously by rotating the covered cylinder hand-over-hand at least 10 times. Be sure the soil is thoroughly mixed in the solution and does not stick to the bottom of the cylinder. Also, try not to let any of the soil suspension leak out the top.
11. Gently set the cylinder down in a safe place, and immediately begin timing with a stop watch or clock with a second hand.
12. Record the time that the cylinder was set down to the second.
13. After $1\frac{1}{2}$ minutes, carefully lower (do not drop) the hydrometer into the cylinder and allow it to float in the soil suspension. Steady the hydrometer to suppress its bobbing up and down.
14. Exactly 2 minutes after the cylinder was set down, read the line on the hydrometer that is closest to the surface of the soil suspension. See Figure SOIL-P-8.
    Note: Read the hydrometer for the Soil Particle Size Distribution protocol the same way that is read for the *Salinity Protocol.*
15. Remove the hydrometer, rinse it, dry it, and gently put it down in a safe place.
16. Suspend the thermometer in the soil suspension in the cylinder for about 1 minute.
17. At the end of 1 minute, remove the thermometer from the suspension, read the temperature, and record the result on the Data Work Sheet.
18. Rinse the thermometer off and dry it.
19. Allow the cylinder to sit safely without being disturbed.
20. Take another hydrometer measurement in the undisturbed cylinder at 12 minutes. Place the hydrometer carefully in the suspension about 30 seconds before taking the reading to allow it to settle.
21. Take and record another temperature reading for the suspension.
22. Rinse the hydrometer and thermometer off when they have been removed from the suspension and dry them.
23. Record these results on the Particle Size Distribution Data Work Sheet.
24. Leave the cylinder undisturbed for 24 hours (or until the beginning of the same class period the next day). **Note:** this time period is critical and should not be significantly longer than 24 hours.
25. Take another hydrometer and temperature reading.
26. Record the results on the Data Work Sheet.
27. Discard the soil suspension by pouring it into a special pail, and spill the contents outside in a place for discarding soil materials. DO NOT pour the suspension down the sink!
28. Carefully rinse and dry the hydrometer, thermometer, beakers, and cylinders, and repeat the above steps 2 more times for the same horizon so that you have a total of 3 sets of results for this horizon.

Note: This measurement involves considerable waiting time and must be done for three samples from each horizon in the soil profile. The number of days required to complete the set of measurements depends on the amount of equipment available. After a sample is mixed with dispersing solution and water initially, it should stand for a day before proceeding to do the measurement, and after the first two measurements, the sample sits undisturbed for 24 hours more. If your soil profile has five horizons, this task must be done 15 times. If only one 500 mL cylinder is available, the measurement of all the samples must be spread out over many days. Having multiple 500 mL cylinders would allow you to accelerate this process. One hydrometer should be adequate for use with at least three cylinders if the starting times of the settling are staggered by about three minutes. However, a single 500 mL cylinder and hydrometer are adequate for use in the *Hydrology Investigation Salinity Protocol*, and if your students will be doing the soil characterization only a few times spread over several school years, then the same cylinder and hydrometer can be reused and the particle size distribution measurements spread over several weeks to save on equipment costs.

How to Measure pH

Make this measurement on three samples for each horizon.

Mix Soil and Distilled Water

1. In cup or beaker, mix dried and sieved soil with distilled water in a 1:1 soil to water ratio (e.g. mix 20 g of soil with 20 mL of water, mix 50 g of soil with 50 mL of water). Mix enough soil and water so that the pH reading can be made in the *supernatant* (the clearer liquid above the settled soil particles). Use a spoon or other utensil but not your hands to transfer the soil. Oils and other materials on your hands may contaminate the pH reading. Stir with a spoon or other stirrer until the soil and water are thoroughly mixed.
2. Stir the soil-water mixture every 3 minutes for 15 minutes. After 15 minutes, allow the mixture to settle until a supernatant forms (about 5 minutes).

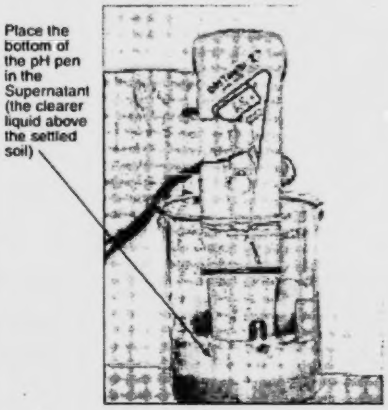
With pH paper (Beginning Level):

1. In a cup or beaker, measure the pH of the water you are using for this protocol by dipping the pH paper into the water and comparing the color to the color chart (as described in the *Hydrology Investigation pH Protocol*).
2. Measure the pH of the supernatant by dipping the pH paper into it (following the procedure given for pH paper in the *Hydrology Investigation*).
3. Record your results on the Soil pH Data Work Sheet.

With the pH pen or meter (Intermediate and Advanced Levels):

1. Calibrate the pH pen or meter with the buffer solutions of known pH following the procedure outlined in the *Hydrology Investigation* for Calibration.
2. In a cup or beaker, measure the pH of the water you are using for this protocol by placing the pH pen or meter into the water and reading the value indicated.

Figure SOIL-P-9


Place the bottom of the pH pen in the Supernatant (the clearer liquid above the settled soil)

The pH of this soil is 6.5

3. To measure the soil pH, place the electrode of the pH pen or meter into the supernatant. See Figure SOIL-P-9.
4. Record your results on the Soil pH Data Work Sheet.

How to Measure Soil Fertility

Part 1: Preparation and Extraction

1. Fill the extraction tube from your Soil Test kit to the 30 mL line with distilled water.
2. Add 2 *Floc-Ex* tablets. Cap the tube and mix well until both the tablets have disintegrated.
3. Remove the cap and add one heaping spoonful of soil (about 5 mL).
4. Cap the tube and shake for one minute.
5. Let the tube stand until the soil settles out (usually about 5 minutes). The clear solution above the soil will be used for the nitrate nitrogen (N), phosphorus (P), and potassium (K) tests.

Note: For some soils, especially those with a high clay content, there may not be enough clear solution extracted. If more clear solution is needed, repeat Steps 1 - 5.

Part 2: Nitrate Nitrogen (N)

1. Use the pipette to transfer the clear solution above the soil to one of the test tubes in the Soil Test Kit until the tube is filled to the shoulder. (If there is not enough solution to fill the tube to the shoulder, repeat Part 1).
2. Add one Nitrate WR CTA Tablet. Sometimes the tablets may break into small pieces, so be sure that all the pieces of the tablet are added to the test tube. Cap and mix until the tablet disintegrates.
3. Rest the test tube in a cup or beaker. Wait 5 minutes for color to develop. Do not wait longer than 10 minutes.
4. Compare the pink color of the solution to the Nitrogen Color Chart in the Soil Test Kit. Record your results (High, Medium, Low, or None) on the Soil Fertility Data Work Sheet.
5. Discard the solution and wash the tube and the pipette with distilled water.
6. Repeat this procedure with the liquid from each of the soil samples. Be sure to rinse the pipette and tube with distilled water after each use.

Part 3: Phosphorus (P)

1. Use the clean pipette to transfer 25 drops of the clear solution above the soil to a clean test tube. (If there is not enough solution, repeat Part 1).
2. Fill the tube to the shoulder with distilled water.
3. Add 1 Phosphorus Tablet to the tube and cap it. Sometimes the tablets may break into small pieces, so be sure that all the pieces of the tablet are added to the test tube. Mix until the tablet disintegrates.
4. Rest the test tube into a cup or beaker. Wait 5 minutes for color to develop, but no longer than 10 minutes.
5. Compare the blue color of the solution to the Phosphorus Color Chart in the Soil Test Kit. Record your results (High, Medium, Low, or None) on the Soil Fertility Data Work Sheet.
6. Discard the solution and wash the tube and the pipette with distilled water.
7. Repeat this procedure with the liquid from each of the soil samples. Be sure to rinse the pipette and tube with distilled water after each use.

Part 4: Potassium (K)

1. Use the clean pipette to transfer the clear solution above the soil to a clean test tube until it is filled to the shoulder. (If there is not enough solution to fill the tube to the shoulder, repeat Part 1).
2. Add 1 Potassium Soil Tablet to the tube. Sometimes the tablet may break into small pieces, so be sure that all the pieces of the tablet are added to the test tube. Cap and mix until the tablet disintegrates. **Note:** This tablet may take longer to dissolve than the others.
3. Compare the cloudiness of the solution in the test tube to the Potassium Color Chart in the Soil Test Kit. Hold the tube over the black boxes in the left column, and compare its shade and cloudiness to the shaded boxes in the right column. Record your results (High, Medium, Low, or None) on the Soil Fertility Data Work Sheet.
4. Discard the solution and wash the tube and the pipette with distilled water.
5. Repeat this procedure with the liquid from each of the soil samples. Be sure to rinse the pipette and tube with distilled water after each use.

Data Submission

Record your data on the Bulk Density, Soil Particle Size Distribution, Soil pH, and Soil Fertility Data Work Sheets. More than one copy of a data work sheet may be required to describe a profile, so be sure to have extra copies. Staple together the sheets for the same soil profile so that records are kept together. Submit your findings to the GLOBE Student Data Server.

Part Two:
Soil Moisture and Temperature

Introduction

This section introduces material common to three standard protocols and a fourth optional protocol for advanced students. The protocols are all related to soil moisture and temperature. To begin, students will use a simple procedure to measure soil moisture. They will weigh a soil sample, dry it out, and weigh it again. The difference in weight is the moisture in the soil that was dried out. An optional protocol for advanced students involves the use of gypsum blocks and a soil moisture meter to take daily readings of soil water content. Two new protocols measure other important soil properties. The rate water flows into the soil (infiltration) is measured using two concentric cans. Soil temperature is measured using a short dial or digital probe thermometer.

Study Site for the Investigation

Generally, the Soil Moisture Study Site should be in the open, with no canopy overhead, and within 100 m of the Atmosphere Study Site or a supplemental Atmosphere Study Site with at least a rain gauge. Depending upon which sampling strategy is used (see below) you may need an area 10 m in diameter characterized by low slopes, homogeneous soil characteristics, natural soil moisture, and uniform sunlight conditions. It is useful to make soil characterization, soil temperature, and infiltration measurements within the same homogeneous 10 m area so that they can all be related to the soil moisture measurements. Some schools may choose a larger site with an area 10 m by 60 m which meets most of the criteria summarized above but which can include some variations in slope and other characteristics.

Your Soil Moisture Study Site(s) should be:

Unirrigated. Since we want to investigate the soil's response to the sun and natural precipitation, it is important that your site be unirrigated.

Uniform. Soil moisture can vary significantly across short distances. The challenge is to find an area where the soil moisture is representative of your site. Look for a relatively flat site that has uniform soil properties and vegetation.

Relatively undisturbed. Sample soils at least three meters from buildings, roads, paths, playing fields, and other sites where the soil may be compacted or heavily disturbed by human activity.

Safe for digging. Check with local utility companies and site maintenance staff to ensure that you do not dig into or disturb a utility cable, buried pipe, or sprinkler irrigation system. You will not be digging below one meter.

Frequency

Measure soil moisture at regular intervals, twelve times each year. Select a period during which you would normally expect the soil at your study site to undergo significant moisture changes. Observations of soil moisture should not be made when the ground is frozen . Weekly measurements during the beginning of your dry season will help predict plant growth. Monthly observations throughout the year or measurements every three weeks during a nine or ten month school year will provide insight into important seasonal variations.

Take your observations at the same time every day, and avoid early morning when dew is present. Soil moisture changes slowly so that the time of your observations is not critical. Taking all the measurements at one time of day ensures that any small daily cycles, particularly in near surface soil moisture, will not confuse your weekly to monthly observations.

Measure soil temperature once per week and on the same date and at the same location as your soil moisture measurements. If your school is not measuring soil moisture, take soil temperature measurements within 10 m of your Atmosphere Study Site following the sampling strategy for temperature given under *Collecting in a Star Pattern*. Weekly temperature measurements should be taken within one hour of local solar noon. Every three months, preferably during March, June, September and December, make soil temperature measurements every two to three hours during the daytime for two consecutive days to determine the diurnal temperature variation at your site.

Measure soil infiltration three times during the course of your annual soil moisture investigation, ideally around the beginning, middle and end of that observation period, and on the same day you sample soil moisture. If you measure soil moisture monthly, measure infiltration seasonally.

Sampling Strategies and Site Layout

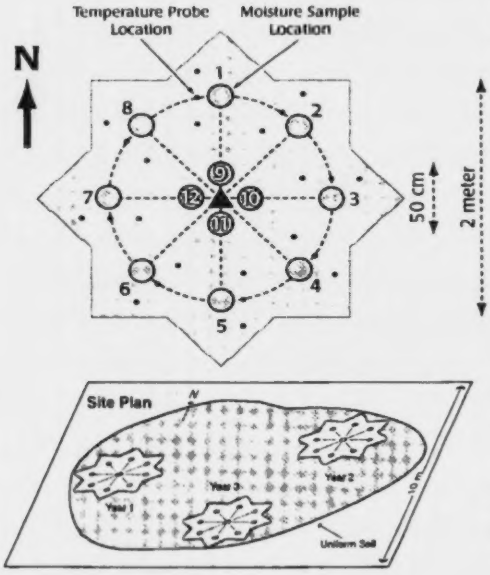
Materials and Tools

GLOBE Science Notebooks and pencils
Compass and 50 meter tape
25 cm ruler, meter stick
Trowel

Collecting in a Star Patten (6 containers)

Measurements are taken in a star-shaped pattern with samples collected each time at different locations on the star. Soil moisture samples will come from a depth of 0 to 5 cm and at a depth of 10 cm. Each time, three samples should be acquired (1 primary sample and 2 additional samples within 25 cm) for quality control purposes. Take three soil temperature measurements at depths of 5 cm and 10 cm within 25 cm of the sampling point following the *Soil Temperature Protocol.*

Figure SOIL-P-10: "Star" Sampling Pattern



Layout a simple star two meters in diameter by using a meter stick and compass to locate four points approximately one meter north, south, east and west from a central reference marker. Locate four more points halfway between these points along an imaginary circle connecting these points. You now have eight points on your star. Four more points should be located 25 cm from the reference marker along the north - south, east - west lines. Every year, select a new reference marker within ten meters of the previous year's star and repeat this pattern. It should take less than ten minutes to collect your six soil moisture samples using a trowel.

Collecting Along a Transect (13 containers, 50 m tape or cord marked every 5 m)

Students with access to an open, natural field are encouraged to take measurements along a transect. The soil samples will come from the top 5 cm of soil. Each time, thirteen samples will be acquired - ten regular samples along the transect and one triplicate sample (1 sample along the transect plus 2 additional samples within 25 cm of the first) for quality control purposes.

Layout your transect along a straight line 50 meters long across an open area within 100 m of a rain gauge, if possible. Measure soil moisture every five meters along this line. Place a permanent flag or marker at the ends of your transect. Use the knotted cord or a measuring tape to locate these sampling points. Orientation does not matter, but please record the orientation as a comment on the Study Site Work Sheet and report it on the Study Site Definition Data Entry Sheet. The next time you sample the transect, shift each of your data collection points 25 cm to avoid the previously disturbed area. It might take an hour to layout and sample a transect, especially if students are sharing equipment and observing other surface and soil characteristics.

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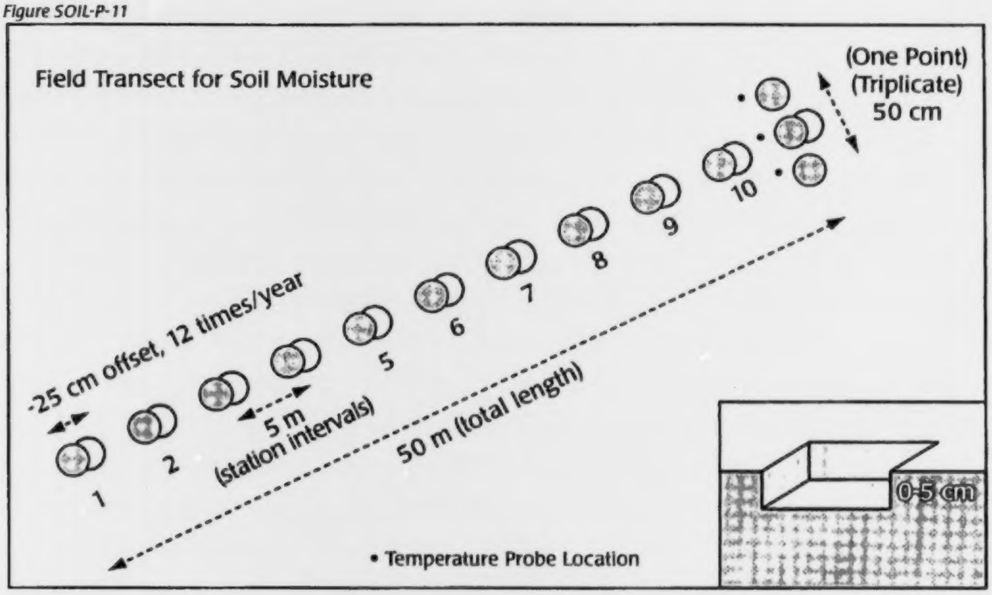
Figure SOIL-P-11


Field Transect for Soil Moisture
(One Point)
(Triplicate)
50 cm
-25 cm offset, 12 times/year
1
2
5 m
(station intervals)
5
6
7
8
9
10
50 m (total length)
0-5 cm
• Temperature Probe Location

Collecting at Different Depths (5 containers, auger)

Students take measurements in a star-shaped pattern, collecting samples each time at different locations on the star. Soil samples from all five depths will be collected from the same hole. Use a trowel to sample from the top 5 cm and an auger to sample at the four deeper depths (10, 30, 60, 90 cm). Unlike the previous two sampling strategies that are designed strictly for open areas, this one can be done in the open or under a canopy, depending upon what data comparisons you wish to make (e.g. comparing soil moisture to evaporation or tree growth). Layout a star pattern as described above to locate the sampling holes around a central reference marker. If your auger strikes an obstruction, offset by 25 cm and try again. Depending upon conditions, a hole 90 cm deep might take 30 minutes to auger and sample.

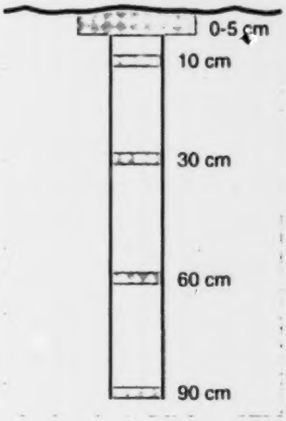

0-5 cm
10 cm
30 cm
60 cm
90 cm

Figure SOIL-P-12

Advanced students in areas where soils are not strongly acidic are encouraged to consider using the *Optional Gypsum Block Soil Moisture Protocol*.

Gravimetric Soil Moisture Protocol

Purpose

To measure the water content of the soil

Overview

Soil moisture samples are collected following one of three sampling strategies. In each case, there are three basic steps:

1. collecting soil samples
2. weighing, drying, and reweighing soil samples
3. data submission

Time

Up to 15 minutes to collect each sample, 15 minutes for first weighing, 15 minutes for second weighing, samples dry in oven overnight

Frequency

Twelve times per year, at regular intervals (weekly to monthly)

Level

All

Key Concepts

Soil holds moisture.

Soil moisture increases after precipitation, and the amount of this increase depends on many factors.

Soil moisture decreases under dry, sunny conditions, and the rate of soil drying also depends on many factors.

Skills

Sampling soil

Using a balance

Recording data

Materials and Tools

GLOBE Science Notebooks and pencils

Soil Moisture Data Work Sheet (Star or Transect)

Trowel or appropriate auger

5-13 soil collection containers (soil sample cans, small glass jars with tight-fitting lids, etc.)

Adhesive tape and pens with which to label the soil cans

Soil drying oven

Thermometer (capable of measuring to 110° C)

Balance or scale with 0.1 g sensitivity

Hot pad or oven mitt for removing cans of soil from ovens

Meter stick

Preparation

Locate the soil moisture site.

Decide upon the sampling frequency and strategy.

Assemble the necessary materials.

Prerequisites

It is useful to have a rain gauge nearby and to have performed the *Soil Characterization Protocols* on your Soil Moisture Study Site.

How to Collect Soil Moisture Samples

Preparation for Collecting Samples

1. Review procedures, site sampling strategy, and layout.
2. Label each can with a unique identification number.
3. Record the location of the site and site description.
4. Locate the sampling point.

Procedures for Star and Tansect Sampling

1. Note your surface cover type. Is it short grass (<10 cm), long grass, or bare soil? Scrape or pull this away. Note if there are any trees overhead or nearby.
2. Dig a hole 10 cm in diameter down to 5 cm. Leave this soil loose in your hole.
3. Sort out and remove any rocks or pebbles larger than a pea (about 5 mm) and remove any worms, grubs, or other animals.
4. Fill your soil collection container about 3/4 full with approximately 100 g of soil.
5. Number the container and record the date, time, depth and can number on your Soil Moisture Data Work Sheet.
   For Transect, skip to Step 9.
6. Remove the soil down to a depth of about 8 cm.
7. Dig the soil in the hole down an additional 4 cm leaving this soil in the hole.
8. Repeat steps 3, 4, and 5 for this 4 cm deep soil layer.
9. Carefully return remaining soil to the hole.
10. Seal the container and store away from heat or sunlight for transport back to the lab or classroom.
11. Take one soil temperature measurement within 25 cm of each soil sampling point at depths of 5 and 10 cm following the *Soil Temperature Protocol*.

Procedures for Depth Sampling

1. Take a sample of the top 5 cm of soil following Steps 1 - 5 as given for *Star and Transect Sampling*.
2. Auger a hole down to just above the first target depth (10 cm).
3. Use the auger to obtain a soil sample of approximately 100 g.
4. Collect the soil sample centered at the target depth.
5. Sort out and remove any rocks or pebbles larger than pea size (about 5 mm) and remove any worms, grubs, or other animals.
6. Fill a soil container about 3/4 full (about 100 g).
7. Number the container and record the date, time, depth and the container's number on your data sheet.
8. Seal the container tightly and store it away from heat or sunlight.
9. Repeat steps 1 - 8 at each depth (30, 60, 90 cm) using the same hole.
10. Carefully return the remaining soil into the hole.
11. Take three soil temperature measurements at depths of 5 cm and 10 cm within 25 cm of the sampling point.

How to Weigh and Dry the Samples

Preparation for Weighing and Dying Samples

1. Preheat the oven.
2. Calibrate the balance with a standard weight to ensure its accuracy.
3. Record the weight of the standard to the nearest 0.1 g in your GLOBE Science Notebook. The weight must be within 0.25 g of the previously recorded standard weight.

Weighing and Dying Procedure

1. Remove any tape from the can that contains the sample soil and uncover the sample.
2. Weigh the soil collection container with the soil sample in it. This is the *wet weight*.

3. Record the date and time at which the sample was collected, the container's number, and the wet weight to nearest 0.1 g on your Soil Moisture Data Work Sheet.
4. Dry the soil by placing the uncovered can in a drying oven using the following minimum conditions:

   Ventilated drying oven, 95° to 105° C, 10 hours,

   Dehydrating oven, 75° to 95 °C, 24 hours

   Microwave oven, high power, microwave safe container only, repeated 5 minute intervals until the sample(s) do not change in weight by 0.25 g from one drying to the next.
5. Remove the can from the oven with the hot pad or oven mitts. Let it cool for five minutes.
6. Re-weigh the soil collection container with the soil in it to obtain the *dry weight*.

   Note: If you are concerned that a sample is not totally dry, remove it from the oven, weigh it, and return it to the oven for 10 hours. If the weight does not decrease by 0.25 g, then it is dry.
7. Record the drying time, the type of drying oven used, and the dry weight to the nearest 0.1 g on your Soil Moisture Data Work Sheet. Calculate the water weight by subtracting the dry weight from the wet weight.
8. Empty the soil out of each container and wipe the can clean with a paper towel.
9. Weigh the dry, empty soil collection container to determine the container weight.
10. Record the container weight to the nearest 0.1 g on your Soil Moisture Data Work Sheet, and calculate the dry soil weight by subtracting the container weight from the dry weight.
11. Calculate the Soil Water Content by dividing the water weight by the dry soil weight, and record your result on the Soil Moisture Data Work Sheet.
12. Repeat steps 1 - 11 for each soil sample.

Data Submission

Report the following information to the GLOBE Student Data Server:

- Date and time of sampling
- Container number
- Depth (in cm)
- Wet weight (in grams)
- Dry weight (in grams)
- Container weight (empty, in grams)
- Drying method (select one of: 95-105 C oven, 75-95 C oven, Microwave)
- Average drying time (in hours and/or minutes)
- Current conditions: Is the soil saturated? (select either YES or NO)
- Station spacing of your transect, if used

Students can calculate the soil water content (SWC) defined below, or let the GLOBE Student Data Server make this calculation. Making this calculation and entering it on the Data Entry Sheet is helpful as a quality control check. If the SWC calculated by students is different by more than 1% from the value calculated by GLOBE, a warning message will appear. In this case, students should make sure that the weights were entered correctly and check their calculations.

In addition, please enter the following information using the Define a Soil Moisture Study Site Data Entry Sheet:

- GPS location of the study site (the center of the star, gypsum block hole, or reference marker at one end of the transect)
- Distances and directions to other related sites (rain gauge, max-min thermometer, closest soil characterization sample location)
- How would you describe the surface of your site? Select one: natural, plowed, graded, backfill soil, compacted soil, or something else (other)
- How would you characterize the surface cover? Select one, Primarily: bare soil, short grass (<10 cm), or long grass (>10 cm)

- How would you describe the canopy cover? Select one: Open, Some trees within 30 m or Canopy overhead (answer this question assuming growing season conditions)
- Soil classification (using the Soil Characterization Data Entry Sheet for these data)

  Describe and report as many soil characteristics as possible following the protocols in *Part One* of this investigation.
- Land Cover classification

  Classify your Soil Moisture Study Site as instructed in the *MUC System Protocol* and report the Level 4 MUC code and land cover name.

Optional Gypsum Block Soil Moisture Protocol

Purpose

To measure the water content of the soil based on the electrical resistance of gypsum blocks

Overview

The Gypsum Block Protocol consists of:

1. installing gypsum blocks at 10, 30, 60, and 90 cm depths
2. reading the soil moisture meter
3. calibrating the gypsum blocks
4. creating a calibration curve

Time

10 minutes per day

Initial calibration requires doing the Gravimetric Soil Moisture Protocol for the 30 cm depth about 20 times over six to eight weeks.

Level

Advanced

Frequency

Daily

Re-installation and calibration of gypsum blocks should be done annually.

Key Concepts

A Gypsum block's electrical resistance is related to soil moisture and is a function of its wetness.

Local conditions affect the saturation of gypsum blocks and requires us to calibrate them.

Soil moisture increases after precipitation.

The amount of increase in soil moisture after precipitation depends on many factors.

Soil moisture decreases on dry, sunny days.

The rate of soil drying depends on many factors.

Skills

Sampling soil

Using a balance

Using a soil moisture meter

Recording data

Materials and Tools

Auger

Meter stick

Four gypsum blocks

Four 10 cm long x 7.6 cm diameter PVC tube or tin cans for wire holders at the surface

Two 4-L soil holding/mixing buckets

Water for making mud balls (1 L)

One 1 m x 2 cm PVC guide tube

Soil packing stick (e.g. an old broom handle)

GLOBE Science Notebooks and pencils

Soil moisture meter

Graph paper

Calculator

Materials for the *Gravimetric Soil Moisture Protocol*

Preparation

Locate the soil moisture site.

Determine and report the requested soil moisture site metadata.

Collect the tools and materials.

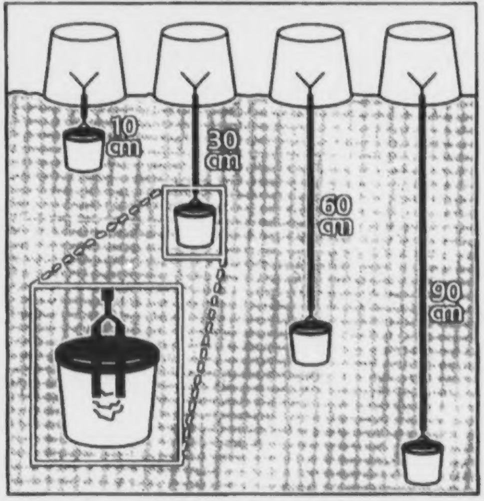
Prerequisites

It is useful to have a rain gauge nearby and to have performed the Soil Characterization protocols at your Soil Moisture Study Site.

Installation of Gypsum Blocks

1. Place the gypsum blocks into a container of water and soak for 5 minutes.
2. Auger a hole to the appropriate depth for each gypsum block sensor (10, 30, 60 and 90 cm). A soil auger works like a cork screw - simply lean on the handle as you turn it. It is best to remove the auger-bucket from the hole after each 360° turn and clean the soil out of the bucket. If you fill it too full, it will be very difficult to remove the soil. Place the extracted soil in a large pail to keep the site clean. The four holes should be placed next to one another in sequence to reduce potential confusion while taking readings and recording data.
3. Put two large handfuls of the soil extracted from the hole into a small bucket or similar container. Add a small amount of water and stir to create a mud ball. The mud ball should stick together. Remove any rocks.
4. Drop the mud ball to the bottom of the hole. Make sure it reaches the bottom.
5. Place the wire lead from one of the sensors through the PVC guide tube.
6. Grab the end of the lead and pull the sensor up tight against the end of the pipe. Lower the sensor into the hole while holding it against the end of the pipe. Holding the wire lead tightly at the top of the pipe, gently push the pipe down to seat the sensor in the mud at the bottom of the hole. **Note:** Since it is difficult to pack soil tightly around the sensor, the purpose of the mud is to establish good contact between the sensor and the soil particles.
7. Hold the sensor in place with the pipe while you begin to backfill the hole. Add just a few handfuls of soil and gently tamp with a broom stick or similar pole. Then add a little more soil and remove the pipe as you tamp. Continue adding soil a few handfuls at a time and tamping firmly as you backfill the hole. Hold on to the wire lead as you backfill so that it will come straight to the surface.

Figure SOIL-P-13: Installed Gypsum Blocks Configuration



8. Place a short piece (about 10 to 20 cm long) of PVC pipe, tin can, or coffee can (with the top and bottom removed) around the wire lead at the surface to protect it and make it more visible to anyone walking in the vicinity.
   8.1. First, label the pipe or can with the appropriate sensor depth.
   8.2. Put the wire through the pipe or can and press the pipe or can 2 to 5 cm into the soil to keep it in place. Do not cut the wire, but wind up the free end extending out of the ground and place it in the pipe or can to keep it out of the way between measurements.
   8.3. A small empty can (soup, etc.) should be inverted over the end of the PVC pipe to keep the rain out.
9. Repeat the above steps for each sensor.

Do not report measurements for a week after installation. The sensors require at least one week to equilibrate to natural conditions. The wire leads are fragile, especially where they connect to the meter. If the end of the wire leads to the gypsum blocks break, peel back the wire insulation and make new leads. It is important to leave enough wire above the ground for this.

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Reading the Soil Moisture Meter

Congratulations! Your gypsum blocks are installed. Wait at least one week before beginning to take data which you report to the GLOBE Student Data Archive. After this, monitor your gypsum blocks daily for soil moisture variations. This is the fun and easy part of this investigation. Do not monitor the blocks when the ground is frozen.

Preparation

Test the soil moisture meter to ensure it is functioning properly according to the manufacturer's instructions. Do this before each use.

How to Make a Soil Moisture Reading

1. Obtain the reading for each gypsum block.
    1.1. Connect the soil-moisture meter to the wire leads of the gypsum block located at the 10 cm depth.
    1.2. Push READ button. Wait for the meter to reach a constant value - it should not be negative.
    1.3. Record the date, time, current soil conditions (CC's), and soil moisture meter reading on the Daily Gypsum Block Data Work Sheet in the appropriate depth column.
    1.4. Disconnect the meter and store the wire leads.
    1.5. Replace the cover over the PVC pipe.
    1.6. Repeat steps 1.1 - 1.5 for each of the remaining gypsum blocks (30, 60, 90 cm).
2. Report all four meter readings to the GLOBE Student Data Server.
3. Convert each meter reading to soil water content using the calibration chart.

How to Use the Daily Gypsum Block Data Work Sheet

There are numbers 1 to 0 in the far left column. Please keep a running count of your measurements by adding a tens digit as you accumulate more data. This allows someone reviewing your data sheets to ascertain if any pages are missing. There is also space to plot your data in the field as you collect it. You would normally expect gradual transitions except for the rapid increase in soil moisture after a rain.

Calibration of Gypsum Blocks

The gypsum blocks must be calibrated so that the meter reading you make can be related to soil water content (SWC). This process can take 6-8 weeks, depending upon how quickly your soil moves through its full drying cycle. Rather than calibrate your gypsum blocks at every depth, we have adopted a policy of basing each calibration on observations made from the 30 cm sensor. Technically, this assumes your soil profile is uniform and your gypsum blocks are identical. It takes about 30 minutes to complete the steps below. You may calibrate your gypsum blocks at 10, 60, and 90 cm depths using the same procedure if you wish.

What To Do and How To Do It

1. Take a soil meter reading from the 30 cm gypsum block sensor.
2. Select a random location within 5 m of the gypsum block hole.
3. Clear surface debris.
4. Auger to 30 cm and collect a 100 g sample centered at this depth. Place the soil sample in a container and number the container.
5. Backfill the hole and replace the surface cover.
6. Record the date, time, depth and container number.
7. Follow the instructions for *Weighing and Drying The Samples* found in the *Gravimetric Soil Moisture Protocol* and make a note of your drying method and average drying time.
8. Record on the Annual Gypsum Block Calibration Data Work Sheet the date and time of your measurement, the wet, dry, and container weights and the soil moisture meter reading that you obtained. There is also space to calculate soil water content (SWC).
9. Repeat steps 1 - 8 about twenty times as the soil moves through one or two complete drying cycles. Wait until your meter reading changes 5% before collecting another gravimetric sample. Re-install and recalibrate your gypsum blocks once a year.

Creating a Calibration Curve

How to plot a calibration curve

1. Complete the Annual Gypsum Block Calibration Data Work Sheet using the following formula to calculate the values for Soil Water Content (SWC) for each row of the Work Sheet.

$$SWC = \frac{(\text{wet weight} - \text{dry weight})}{(\text{dry weight} - \text{can weight})} \times 100$$

Remember:

wet weight = wet soil + can
dry weight = dry soil + can

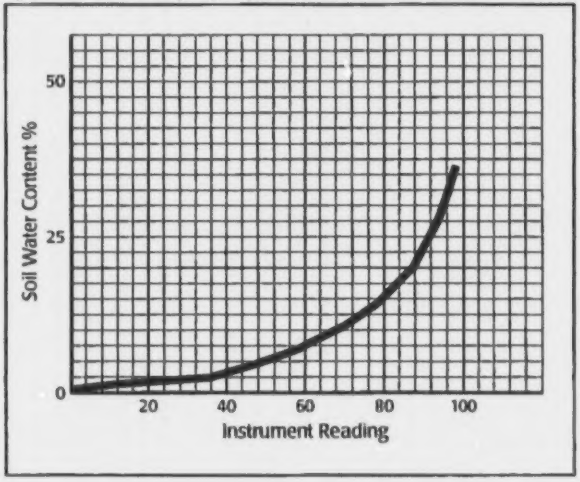
2. Create a graph in which you plot all the soil water content data collected on the Y-axis and all the corresponding soil moisture meter readings on the X-axis. Draw or calculate the *best-fit quadratic curve* through your data pairs, which should span a broad range of soil moistures. This will be your calibration curve, which you will use to convert other meter readings to soil water content.

If you have any questions about creating your calibration curve or if you need any assistance with the curve, the principal investigator for the *Soil Moisture Investigation* is glad to provide answers and assistance and can be contacted at the addresses given in the *Welcome Section*.

When you have finished determining your calibration curve, please mail or email a copy of your curve and of your corresponding Annual Gypsum Block Calibration Data Work Sheet to GLOBE Student Data Archive at the address given in the *Implementation Guide*.

During the year, if you get readings either higher or lower than any of the readings on your Data Work Sheet, take a gravimetric sample, and use the values you measure for this sample to extend your calibration curve. Send a copy of your revised calibration curve and extended Annual Gypsum Block Calibration Data Work Sheet to the GLOBE Student Data Archive.

Figure SOIL-P-14: Example of a Gypsum Block Calibration Curve



30 cm

Date	Reading	SWC
2/4/97	42	7
2/25/97	17	3
3/6/97	96	35
3/8/97	91	25
3/18/97	70	14

Infiltration Protocol

Purpose

To determine the rate at which water soaks into the ground as a function of time

Overview

Two nested cans are pushed into the soil and water is added to both to a depth of at least 5 cm. The time it takes water to drop a fixed 2 - 4 cm distance is recorded and the measurement is repeated. Infiltration measures how easily water moves vertically through the soil and this can indicate how flood-prone an area is.

Time

One class period to build and test the double-ring infiltrometer

45 minutes or one class period for the measurement

This protocol can be done while samples are collected for the *Gravimetric Soil Moisture*

Level

All

Frequency

Three or four times a year at the Soil Moisture Study Site

One time at a Soil Characterization Sample Site

In all cases three sets of measurements should be taken within a radius of 5 m.

Key Concepts

Infiltration rate changes depending upon the level of soil saturation.

If water is not stored in the ground, it must evaporate or runoff and may pool on the surface for a time.

Skills

Building an infiltrometer

Testing

Organizing

Observing

Monitoring time intervals

Recording data

Analyzing data

Materials and Tools

Two metal rings the smaller with a diameter of 10 - 20 cm and the other with a diameter 5 - 10 cm larger (Coffee cans work!)

Buckets or other containers to transport a total of at least 8 L of water to the site

Ruler

Waterproof marker

Stop watch or watch with a second hand

Block of wood

Hammer

Three soil sample containers suitable for soil moisture measurement

Grass clippers

Funnel

Prerequisites

None

Background

Infiltration rate is determined by measuring the time it takes the level of water sitting on a soil to drop a fixed distance. This rate changes with time as the soil pore space fills with water and reaches a steady rate, characteristic of water flow through your soil when it is *saturated*. There are three flow regimes you might encounter:

Unsaturated flow- the initial flow rate is high as the dry soil pores fill with water.

Saturated flow - the flow rate is steady and water moves into the soil at a rate determined by soil texture and structure.

Ponding - the flow rate approaches zero when the ground becomes totally saturated and is no longer able to conduct water through its pores.

Preparation

Site selection

Select a location within 2 - 5 m of the Soil Moisture Study Site or of a Soil Characterization Sample Site. Be careful that you do not leave a hose running where the water will flow over your soil moisture sampling points!

Construct a Dual Ring Infiltrometer

Cut the bottom out of your cans.

Use a permanent waterproof marker or paint to partially shade a ring on the inside of the smaller can to use as a timing reference mark. The width of the band or ring should be 20-40 mm and centered roughly 9 cm from the bottom of the can. Many cans have impressed ribs that make good reference marks but it is still necessary to mark them for good visibility.

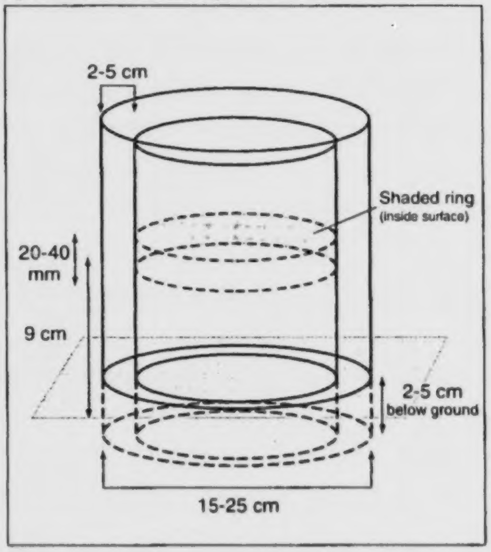
Measure and record the width of your reference band (in mm).

Measure and record the widths of your inner and outer rings (in cm).

Timing

You can use either a stop watch or a watch with a second hand to time the water flow into the soil. When using a stop watch, start it as water is first poured into the inner ring and read elapsed time from it for each start time and end time.

Figure SOIL-P-15: Double-ring Infiltrometer



Practice

Have students practice this protocol, including the timing, so that they become comfortable making the measurements at a site where there is easy access to water and at a time when they can start over and do not have to complete a full 45 minute set of measurements. If students practice in a sandy location, the infiltration time intervals will be shorter and they will get more chances to make measurements.

How to Measure Infiltration

1. Clip any vegetation (grass) to the ground surface and remove all loose organic cover over an area just larger than your largest can. Try not to disturb the soil.
2. Starting with the smaller can, twist the cans 2 - 5 cm into the soil. A hammer may be used to pound the can into the surface. If you must use a hammer, a block of wood should be used between the hammer and the top of the can to distribute the force of the hammering. Do not hammer so hard that the can crumples.

3. Measure the height above ground level of the bottom and top of the band you marked on the inside of the smaller can.
4. As quickly as possible, do the following using a team of 3 - 4 students:
   4.1. Pour water into both rings, and maintain a level in the other ring approximately equal to the level in the inner ring. Note that the water level in the outer ring tends to drop more quickly than that of the inner ring.
   4.2. Pour water into the inner ring, to just above the upper reference mark.
   4.3. Start the stopwatch or note the time to the second and record it on the Infiltration Data Work Sheet.
   Note: The outer ring should not be leaking water to the surface around its rim. If it is, start over in another location, push the outer ring deeper into the soil or pack mud around its base.
5. As the water level in the inner ring reaches the upper reference mark, record the elapsed time as your start time.
6. During the timing interval, keep the water level in the outer ring approximately equal to the level in the inner ring, but be careful not to pour water into the inner ring (using a funnel can help) or to let either ring go dry.
7. As the water level in the inner can reaches the lower reference mark,
   7.1. Record the time as your end time.
   7.2. Figure the time interval by taking the difference between the start and end times.
   7.3. Pour water into the inner ring to just above the upper reference mark. Raise the water level in the outer ring so that they are approximately equal.
8. Continue repeating steps 5 - 7 for 45 minutes or until two consecutive interval times are within 10 sec. of one another.
9. Some clays and compacted soils will be impervious to water infiltration and your water level will hardly drop at all within a 45-minute time period. In this case, record the depth of water change, if any, to the nearest mm. Record the time at which you stopped your observations as the end time. Your infiltration measurement will consist of a single data interval.
10. Remove the rings. WAIT FIVE MINUTES.
11. Measure the near-surface (0 - 5 cm depth) soil moisture from the spot where you just removed the rings. Follow the *Gravimetric Soil Moisture Protocol*.
12. Make two other infiltration measurements within a 5 m diameter area, either at the same time using other groups or over several days (if it does not rain and change near-surface soil water content). It is not critical that multiple runs have the same number of reading sets, but do not submit runs that are incomplete (e.g. A run that was cut short due to lack of time). If you make more than three sets of measurements, submit your three best sets.

Data Analysis and Presentation

Infiltration rate is found from the distance that the water level decreased divided by the time required for this decrease. For your GLOBE measurements this is equal to the width of your reference band divided by the difference between the start and end times for an interval.

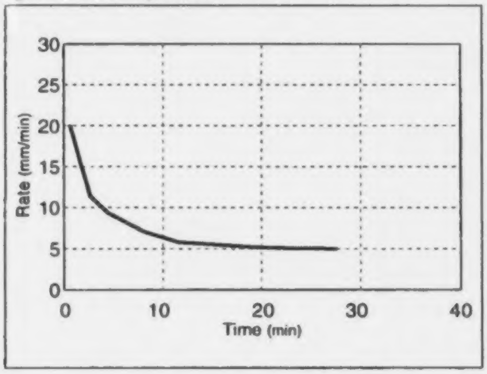
Use the Infiltration Data Work Sheet to record and help calculate the values needed to plot your results. The flow rate we observe for each timing interval is really the average value during that interval. It is best to plot that flow rate at the *midpoint* of the interval times. Infiltration should decrease with time and it is important that you keep track of the *cumulative* time since water was first poured into the inner ring. Look over the table and graph below and make sure that you can use the formulas on the Data Work Sheet to calculate these values before analyzing your own data.

Figure SOIL-P-16
Infiltration Into Jim's Garden

Water Level Change = 20 mm

Time							Flow
Start		End		Interval	Midpoint	Cumulative	Rate
[min]	[sec]	[min]	[sec]	[min]	[min]	[min]	[mm/min]
31	00	32	00	1.00	31.50	0.50	20.0
32	30	34	15	1.75	33.38	2.38	11.43
34	30	36	45	2.25	35.62	4.62	8.89
37	15	40	00	2.75	38.62	7.72	7.27
40	45	44	00	3.25	42.38	11.38	6.15
44	15	47	45	3.50	46.00	15.00	5.71
48	15	52	00	3.75	50.12	19.12	5.33
52	15	56	15	4.00	54.25	23.25	5.00
56	30	00	30	4.00	58.50	27.50	5.00

Figure SOIL-P-17: Infiltration



Soil Temperature Protocol

Purpose

To measure near-surface soil temperature
To detect diurnal changes in soil temperature
To learn about the insulating capabilities of the soil

Overview

Soil Temperatures at 5 and 10 cm depths will be measured using a probe thermometer. Soil temperature is a function of climate, soil, soil moisture, depth and geographic setting. This protocol collects data to explore these interactions.

Time

10-15 minutes per measurement set
(6 probe measurements)

Level

All

Frequency

Weekly: three measurements each at 5 and 10 cm depths

Seasonally: one measurement each at 5 and 10 cm depths every 2 to 3 hours during the daytime on two consecutive days

Key Concepts

Soil is an insulating layer.
Soil temperature varies with depth, soil moisture, and air temperature.
Soil temperature varies less than air temperature.

Skills

Reading dial scales
Field *sampling*
Observing related phenomena
Graphing temperature cycles

Materials and Tools

Dial or Digital probe thermometer
12 cm finishing nail and hammer
A wooden block with 6 mm diameter hole through it
Calibration thermometer

Preparation

None

Prerequisites

None

Site Selection and Timing

Make measurements adjacent to your Soil Moisture Study Site, or if this is not possible, within 10 m of your Atmosphere Study Site. Study the figures of the star or transect sampling patterns described in the *Sampling Strategies* and *Site Layout* sections which illustrate acceptable sampling locations. If you are making these measurements at your Atmosphere Study Site, follow the sampling pattern and site layout for the Star Pattern.

1. Select a relatively flat sunny area.
2. Try to find an area with uniform characteristics across an area having a diameter of 5 m.
3. The ground should not be compacted but can be covered with litter or grass.
    - Make a note on the Data Work Sheet if it has rained in the past 24 hours.

When making measurements on consecutive days, try to make your readings on days with similar weather conditions and for soil conditions that are typical for the week you are making them. Try to make diurnal readings around the middle of March, June, September, and December.

Preparing for the Field

Your thermometer should be most sensitive to temperature changes about 2 cm from the tip because of the length of the temperature sensor inside the probe. To take measurements at 5 and 10 cm depths, the thermometer will have to be pushed 7 and 12 cm into the ground.

Drill a hole in a wooden block so that when the soil thermometer is pushed all the way into this hole 7 cm of your probe extends beyond the bottom of the block. This will help students maintain a uniform depth for the 5 cm depth measurements.

Get a nail that is the same length and diameter as your thermometer probe or cut a nail to this length.

Calibration:

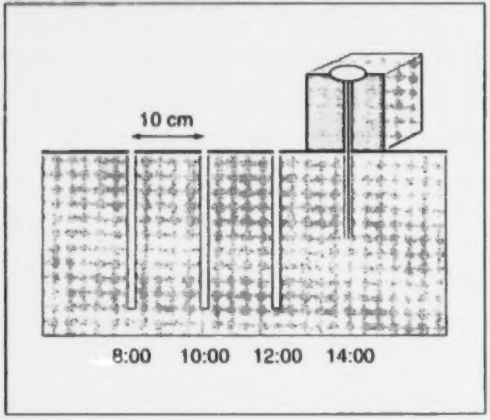
Check the accuracy of your probe every three months. This is particularly important if you are using more than one thermometer, as differences or biases between two thermometers will make your data impossible to interpret. Follow this calibration procedure:

1. Use the calibration thermometer from the Atmosphere Investigation as a calibration standard.
2. Place your thermometers in water at room temperature; record their temperature readings after 2 minutes.
3. There should be less than 2° C difference between your thermometer readings and the calibration thermometer.
4. Follow the manufacturer's directions to reset dial-type thermometers, if your differences are greater than this.

How to Measure Soil Temperature

1. **Make a pilot hole to 5 cm.** Insert the nail through your wood block and push it to 2 cm above the top of the block. If the ground is so hard you have to use a hammer, then complete the pilot hole to its full depth. Remove the nail using a twisting motion. If the ground cracks and bulges up as you remove the pilot nail, offset 25 cm and try again. Try to minimize the amount you disturb the soil.
2. **Insert the thermometer to 7 cm.** Insert the thermometer through your block. Gently push and twist the thermometer until the head is resting on the block. Do not force it as this will damage your instrument.
3. **Read the soil temperature at 5 cm.** Wait at least 2 minutes; read the thermometer. Wait another minute, and reread the thermometer. Repeat until consecutive readings are within 0.5 - 1.0° C of each other. Record this value on the Soil Temperature Data Work Sheet.
4. **Remove the thermometer and the block.** Use a twisting motion - try not to disturb the soil.
5. **Repeat steps 1-4 without the wood block.** Gently push and twist your thermometer fully into the ground using the same hole as before. Instead of depths of 5 and 7 cm, use depths of 10 and 12 cm, respectively.
6. Report your measurements to the GLOBE Student Data Server on the Soil Temperature Data Entry Sheet.

Figure SOIL-P-18: Soil Temperature: Layout of Diurnal Observations



Weekly Measuements

Take three sets of soil temperature measurements adjacent to your current soil moisture star pattern sampling location or next to your Atmospheric weather shelter at 5 and 10 cm depths. Complete these measurements within 1 hour of local solar noon and within a period of 20 minutes. Record your time to the nearest 10 minutes (e.g. if you take the 5 cm reading at XX:06, select the next 10 minute mark, XX:10, as your time of observation.

Diurnal/Seasonal Measuements

Take diurnal temperature measurements every three months, preferably during March, June, September, and December. Repeat the measurements every 2 to 3 hours on two consecutive days. Try to take at least 5 readings per day. Offset each new reading by at least 10 cm. See Figure SOIL-P-18. Read the current temperature at your Atmosphere Investigation Instrument Shelter and record it in your GLOBE Student Notebook each time you measure soil temperature.

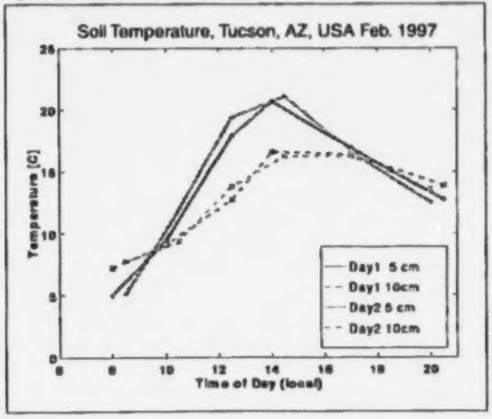
Data Analysis and Presentation

Construct a table in your GLOBE Student Notebook similar to the one below for recording your results or use the Soil Temperature Data Work Sheet. Plot the data using Figure SOIL-P-20 as a guide.

Figure SOIL-P-19: Soil Temperatures Tucson, AZ, USA

	2/12/97			2/13/97		ND=no data
Local Time	5 cm	10 cm	Local Time	5 cm	10 cm	Air Temp
8:00	5.0	7.2	8:30	5.1	7.7	ND
10:00	9.5	9.1	10:30	12.0	9.4	ND
12:00	17.8	13.0	12:30	19.4	13.8	26.2
14:30	20.6	16.5	14:30	21.1	16.3	ND
17:00	16.8	16.3	17:00	16.7	16.3	ND
20:30	13.0	13.9	20:00	12.5	13.6	ND

Figure SOIL-P-20: Soil Temperatures



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Learning Activities

Just Passing Through

Beginning students are introduced to the basic concepts of how water passes through soil in an activity which illustrates the scientific method. More advanced students investigate the effects of soil characteristics on water infiltration and the chemistry of water that has passed through soil.

From Mud Pies to Bricks

Introduces the various particle sizes found in soils and the properties which each contributes to the soil character.

Soil and My Backyard

Students collect, describe and compare soils from their own backyards.

A Field View of Soil and Soil Moisture - Digging Around

Students discover that soil properties such as moisture and temperature can vary considerably across a single landscape.

Soils as Sponges: How Much Water Does Soil Hold?

Students explore soil moisture by weighing and drying sponges and then they explore their soil samples in the same way.

Soil: The Great Decomposer

Students simulate environmental conditions in order to determine which are the key factors in the decomposition of organic material in soil.

Making Sense of the Particle Size Distribution Measurements

Students use the data from the this protocol to determine the texture of soil horizons.

The Data Game

Teams of students play a game in which they gather data and distort the values of certain measurements. They then estimate the values of the measurements taken by other teams and try to detect their errors.

Just Passing Through (Beginner Version)

Purpose

To develop an understanding of how water flows through soils and of how the water changes as it goes through

Overview

Students time the flow of water through different soils and observe the amount of water held in these soils. They will also observe the filtering ability of soils by noting the clarity of the water before and after it passes through the soil.

Time

One class period

Level

Beginning

Key Concepts

Water flows through soil.

Soil holds water.

Soil properties affect flow rate and water holding capacity.

Skills

Asking questions

Developing hypotheses

Testing hypotheses

Observing results

Analyzing results

Drawing conclusions

Timing

Measuring pH

Materials and Tools

(for each team of 3-4 students)

Clear 2 liter bottle

Three 500 mL beakers or similar size clear containers marked off in cm to pour and catch water

Soil sample (Bring in 1.2 L samples of different types of soil from around the school or from home. Possibilities include top soil (A horizons), subsoils (B horizons), potting soil, sand, soils that are compacted, soils with grass growing on top, soils with clearly different textures)

Fine window screen or other fine mesh that does not absorb or react with water (1 mm or less mesh size)

Water

Clock or timer

Note: Smaller containers may be used if desired as long as the soil container sits firmly on the water catchment container. Reduce the amounts of soil and water - but remember that it is important for all students to start with the same amount.

For more advanced beginners:

pH paper, pen, or meter

Preparation

Discuss, with students, some of the general characteristics of soils or do *Soil in My Backyard* or the *Soil Characterization Protocols*.

Prerequisites

None

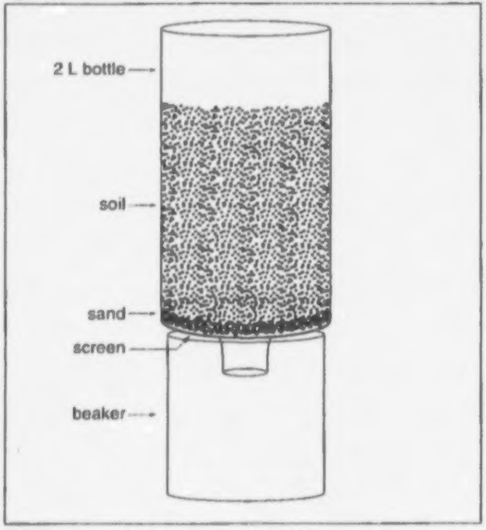
Background

What happens to water when it passes through soil depends on many things such as the size of soil particles (texture and particle size distribution), how the particles are arranged (structure), how tightly they are packed (bulk density), and the attraction between the soil particles and the water. Some types of soil let water flow in quickly, then hold the water inside the soil like a sponge. This might give plants a better chance of using some of that water. Other types of soil may let the water go completely through in just a few seconds. Still other soils may keep the water from getting in at all. None of these soil types is better than the other - they are simply good for different reasons. Which soil property would you look for if you wanted to plant a garden? Build a driveway or a playground? What happens if the soil is full of water and a heavy rain falls on it? How can you change the way your soil holds water? What happens to the soil when organic matter is added, when plants are growing on top of it, when it is compacted, or when it is plowed?

Preparation

- Bring in samples of different types of soil from school or from home.
- Remove the labels and lids and cut off the bottoms of the clear plastic 2 L bottles.
- Place a circle of screen inside the bottle so that it covers the cap opening.
- Pour 3-4 cm of sand onto the screen. The sand will keep the screen from becoming clogged.
- Place the bottle, mesh side down, on a beaker or clear container.
- Pour 1.2 L of soil into the bottle over the sand.
- Copy the Work Sheets for each student

Figure SOIL-L-1



What To Do and How To Do It

Class Investigation

1. Choose a soil (a sandy soil works best) to use for demonstration and place 1.2 L of the soil into the 2 liter bottle.
2. Have students look closely at the soil. What do students notice: Color? Plant matter? Does it feel light or heavy? Granular (like cookie crumbs) or blocky (chunky)? Record their observations about the soil on the board.
3. Pour 300 mL of water into a 500 mL beaker or other clear container for pouring. Have students notice the clarity of the water.
4. Use a black marker to draw a line showing the height of the water in the pouring container. Have students count the cm lines to reach the top of the water. Record this number on the board.
5. Ask the students "*What will happen if you pour the water onto this soil*"? Ask students to explain why they think the soil and water will behave this way when water is poured onto it. Some possible questions to ask are:

- *Will the water run out through the bottom of the bottle?*

- *Will all of it run out? How much will run out?* Make a mark on the pouring container with a red pen to show how much of the water students think will flow out.
- How fast will the water pass through the soil? *Older students may time with a clock or stopwatch. Younger students can time by marking the minutes off on a timer (like in the Work Sheets) as the teacher times.*
- What will the water look like when it comes out the bottom? Clear? Murky? Very Dirty?

6. Record the class 'hypotheses' on the board.
7. Pour the water onto the soil and begin timing. Ask students to describe what is happening as you pour the water:

- Is all the water staying on top?
- Where is it going?
- Do you see air bubbles at the top of the water?
- Does the water coming out of the soil look the same as the water going in?
- Does the soil look different where the water has gone?

8. Record the class observations on the board. Also record how long it takes for the water to pass through the soil.
9. Ask students to compare their hypotheses and the results of the experiment.
10. Once the water has stopped dripping from the bottom of the bottle, remove the soil bottle and hold up the beaker of water which has passed through the soil. Ask students:

- Is this the same amount of water that we started with? How can we tell if it is the same amount?
- *Pour the water back into the original container. Compare the amount left with the black line on the container.* How much water is missing? How could we measure how much is missing?
- *Compare the water level to the red line on the container.* Is there more or less water left than we thought there would be? How could we measure the difference? Why did you think there would be more or less?
- What happened to the water that is missing?
- Is the water more or less clear than before it passed through the soil? Why?

11. Keep the water that was poured through for comparison.
12. Using the bottle of saturated soil, ask students what will happen if you pour another 300 mL of water into the soil. Record the class hypotheses on the board.

- Will the same amount, more, or less water stay in the soil this time?
- Will it move through faster or slower or at the same speed?
- How clear will the water be? The same, more clear, or less clear than before?

13. Pour the water through the saturated soil, keep the time, observe the results, and compare with the hypotheses. Ask students:

- *Did the water flow through faster than before? How do you know?* Compare the two times.
- *Did more of it flow through than before? How can we find out?* Compare the amounts in the beakers.
- *Is the water as clear as the first time?* Compare the color of the water in the two beakers.

Group Investigation

Experimenting with different soils

Discussion

1. Review the properties of the various soil samples that were brought in.
2. Ask students if they think water would pass through all of the types of soils in the same amount of time and if all the soils would hold the same amount of water.
3. Discuss which soils they think might be different.
4. Provide each group of students with one of the various soils.

Observation and Hypotheses

1. Give each student the Look and Guess Work Sheet.
2. Ask the students to fill in the **Color**of their soil (in words or with a crayon).
3. Ask the students to circle the **Structure** which looks most like their soil.
4. Ask students to look for leaves or **Organic matter** in their soil. Circle YES if they find organic matter. Circle NO if they do not.
5. **Time** Remind students of the observations which they made during the demonstration. Ask students to guess the amount of time it will take water to flow through their soil. Circle the time on the timer, then write the number in the blank.
6. **Amount** Ask students to draw a RED line on the container showing the amount of water they think will flow through their soil.
7. **Clarity**Ask students to put an X on the container which will look most like their water after it flows through their soil.

Experiment and Report

1. Explain that when you say 'GO' everyone will pour their water in together.
2. You will begin to time when the water is poured.
3. Have students fill in the Experiment and Report Work Sheet for their soil.

Have each group report on the results of their experiment to the class. Reports should include **Questions, Hypotheses, Observations and Conclusions**about the experiment. Students can use their Work Sheets to prepare their reports.

Further Investigations

1. Using distilled water, have students measure the pH of the water.
2. Predict whether the pH will be different after the water passes through the soil.
3. Pour the water through, then test the pH again.
4. Have students draw conclusions about the affect of soil on water pH.

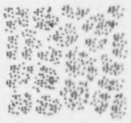
Note: 1. Use this procedure to experiment with conductivity by measuring the conductivity of distilled water before passing it through the soil, then using saltwater and passing it through the soil. 2. Experiment with filtering by using very murky water and passing it through clean sand.

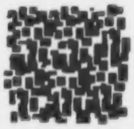
Soil Investigation

Just Passing Through Beginners Work Sheet

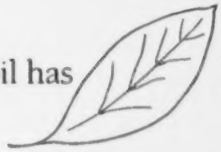
Look and Guess

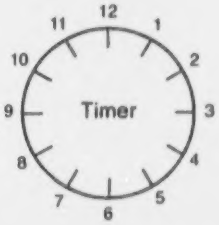
My soil is ______________ color

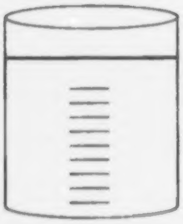




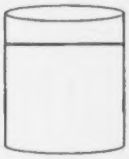
My soil looks granular blocky

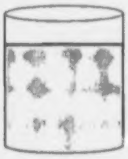
My soil has  leaves. YES NO

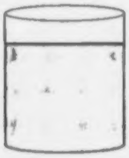
Time _________ 

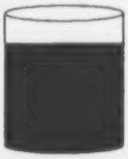
How much water will come out? Make your line RED. 

What will the water look like? (CIRCLE)





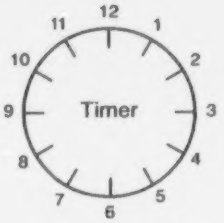




Just Passing Through Beginners Work Sheet (continued)

Experiment and Report

Time ________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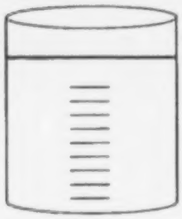
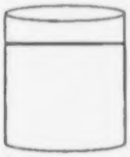
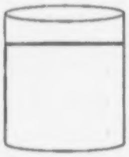
1
2
3
4
5
6
7
8
9
10
11
Timer

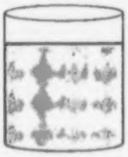
How much water came out?

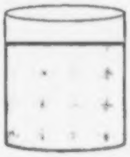


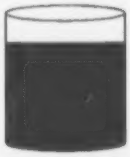
What did the water look like?











My Report

Just Passing Through

Purpose

To develop an understanding of some of the relationships between soils of different types and water

Overview

Students will time the flow of water through soils with different properties and measure the amount of water held in these soils. They will also experiment with the filtering ability of soils by testing the pH of the water before and after it passes through the soil and observing changes to the clarity of the water and to the characteristics of the soil.

Time

One class period for initial activity
2-3 class periods for Further Investigations

Level

All

Key Concepts

Water flows through soil.
Soil holds water.
Water affects soil properties.
Soil properties (particle size distribution or texture, structure, organic matter, layering, etc.) affect flow rate, water holding capacity, nutrient filtering ability, etc.

Skills

Asking questions
Developing hypotheses
Testing hypotheses
Observing results
Analyzing results
Drawing conclusions
Measuring volume
Timing
Measuring pH
Measuring NPK (Nitrogen, Phosphorous, Potassium)

Materials and Tools

(for each team of 3 - 4 students)

2 - 3 clear 2-liter bottles*
4 - 6 500-mL beakers* or similar size clear containers to pour and catch water for the demonstration, more as needed for the class activity. The number of beakers will be dependent on the number of student groups.
Soils samples (Bring in 1.2 L samples of different types of soil from around the school or from home. Possibilities include top soil (A horizons), subsoils (B horizons), potting soil, sand, soils that are compacted, soils with grass growing on top, soils with clearly different textures).
Fine window screen or other fine mesh that does not absorb or react with water (1 mm or less mesh size)
Strong tape
Scissors
Water
Laboratory ring stands with rings, if available (enough to hold the number of plastic bottles to be used). Another approach is to rest the bottles in the top of the beaker (this method does not use the laboratory ring stands). With the soil weight, the bottles will be relatively stable setting in the beakers.
pH paper, pen, or meter
Work Sheet
GLOBE Science Notebooks
For Further Investigations:
Distilled water, salt, vinegar, baking soda
Plastic wrap to cover bottles
Conductivity meter
NPK kit
Growing sod or mulch
Alkalinity kit

- You can use 1-liter bottles and either 400 or 250 mL beakers. The size of the beakers will be dependent on the diameter of the bottles. The bottle with the screen should not descend too deep into the beaker so that it impacts the reading of the volume of water. The smaller size bottle has the advantage of requiring less soil. Regardless of which size bottle is used, it is important that the amount of soil, water and size of the beakers and bottles used in comparative experiments are the same.

Preparation

Discuss with students some of the general characteristics of soils or do *Soil in My Backyard* or the *Soil Characterization Protocols.*

Prerequisites

None

Background

What happens to water when it passes through soil depends on many things such as the size of the soil particles (texture and particle size distribution), how the particles are arranged (structure), how tightly they are packed (bulk density), and the attraction between the soil particles and the water. Some types of soil let water flow in quickly (infiltrate), then hold the water inside the soil (water holding capacity). This might give plants a better chance of using some of that water. Other types of soil may let the water go completely through in just a few seconds. Still other soils may keep the water from getting in at all. None of these soil types is better than the other - they are simply good for different reasons. Which soil property would you look for if you wanted to plant a garden? Build a driveway or a playground? What happens if the soil is full of water and a heavy rain falls on it? How can you change the way your soil holds water? What happens to the soil when organic matter is added, when plants are growing on top of it, when it is compacted, or when it is plowed?

Water in soil is also a key to the transfer of nutrients from the soil to growing plants. Most plants do not eat solid food (although a few do digest insects!) Instead, they take in water through their roots and use the nutrients the water has obtained from the soil. How nutritious is soil? That depends on how the soil was formed, what it was formed from, and how it has been managed. Farmers and gardeners often add *nutrients* or fertilizer to soil so that it will be better for their plants.

Preparation

- Bring in samples of different types of soil from school or from home.
- Collect a number of clear plastic 2 liter bottles with straight sides. Remove the label and lid and cut off the bottom and the top so that the end will fit into a 500 mL beaker or other clear container. Note that some of the curve of the top part of the bottle should be kept so that the bottle will fit into the beaker.
- Cut a circle of a fine mesh window screen or nylon net about 3 cm larger than the opening made in the top of the bottle. Using strong tape, secure the mesh circle around the end of the bottle where the top was cut off.

Place the bottle, mesh side down, on a beaker or set it in a ring stand and place a catchment beaker under it.

What To Do and How To Do It

Class Investigation

1. Observe the properties of the soil samples that will be used. Use your GLOBE Science Notebooks to record information about the soil samples which you observe. Also record where each sample was found and the depth at which it was found. If you have done the soil characterization

protocols, you can also record the moisture status, structure, color, consistence, texture, and presence of rocks, roots and carbonates.

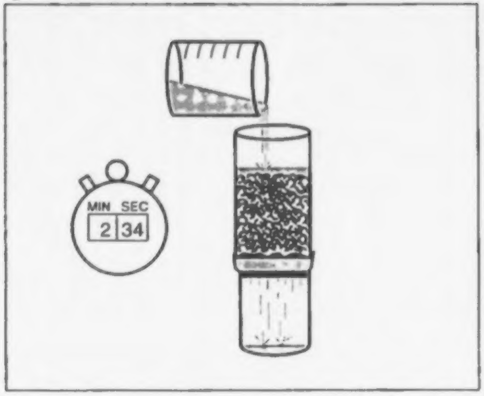
2. Choose one soil (a sandy loam works best) to use as a demonstration and place 1.2 L of the soil in one of the 2 liter bottles.
3. Pour 300 mL of water into 500 mL beaker or other clear container for pouring. Measure the pH of the water. Also, notice the clarity of the water.
4. Ask the students "*What will happen if you pour the water onto this soil*"? Ask students to explain why they think the soil will behave this way when water is poured onto it. Some possible questions to ask are:
    - *How much water will flow out the bottom of the container?*
    - *How fast will the water pass through the soil?*
    - *Will the pH of the water change, and if so, how?*
    - *What will the water look like when it comes out the bottom?*
5. Record the class hypotheses on the board and ask the students to record the hypotheses in their GLOBE Science Notebooks.
6. Pour the water onto the soil and begin timing. Ask students to describe what is happening as you pour the water:
    - Is all the water staying on top?
    - Where is it going?
    - Do you see air bubbles at the top of the water?
    - Does the water coming out of the soil look the same as the water going in?
    - What is happening to the soil structure, especially at the soil surface?
7. Record the class observations on the board and have the students record the information in their GLOBE Science Notebooks. Also record how long it takes for the water to pass through the soil.
8. Ask students to compare their hypotheses and the results of the experiment.
9. Have students record their own conclusions in their GLOBE Science Notebooks about how the water and soil interacted.
10. Once the water has stopped dripping from the bottom of the bottle, measure the amount of water that moved out of the soil into the beaker. Ask students:
    - What happened to the water that is missing?
11. Notice the clarity of the water.
    - Is it more or less clear than before it passed through the soil?
12. Test the pH of the water in the beaker that has flowed through the soil, record the results, and compare the results with the pH of the water that was poured into the soil. Compare with the student hypotheses.
    - Did the pH change?
    - If so, what might have caused this change?
13. Using the bottle of saturated soil, ask students what will happen if you pour another 300 mL of water into the soil. Record the class hypotheses on the board.
    - How much water will stay in the soil?
    - How fast will it move through?
    - Will the pH change?
    - How clear will the water be?
14. Pour the water back through the soil, observe the results, and compare with the hypotheses.
15. Have students record their questions, hypotheses, observations and conclusions in their GLOBE Science Notebooks.

Group Investigations

Experimenting with different soils

1. Review the properties of the various soil samples that were brought in.
2. Ask students if they think water would pass through all of the types of soils in the same amount of time and if all the soils would hold the same amount of water.
3. Discuss which soils they think might be different and how.

Figure SOIL-L-2



4. Have each group of students select one of the various soils.
5. Have each group repeat steps 2 - 15 above on their own soil. Instead of writing hypotheses and observations on the board, the students will record the experiment in their GLOBE Science Notebooks.
6. Have each group report on the results of their experiment to the class. Reports should include questions, hypotheses, and observations regarding the following variables, as well as their conclusions about the variables and how they affected the results of their experiment.
   - soil characteristics
   - original water pH and clarity
   - amount of time for the water to pass through the soil
   - the amount of water which passed through the soil
   - changes in water pH and clarity
   - results of the saturation test.

Note: The information collected in the students' GLOBE Science Notebooks will be used to prepare their papers and reports.

7. Review all results with the class. Have the class determine the soil characteristics, such as different size of particles, space between the particles, organic material which may hold water, etc. associated with the fastest and slowest infiltration, retention of water in the soil, and changes in pH and clarity.
8. Based on the comparison of their hypotheses with the experimental results, record conclusions about how the water and soil interact and how diverse soils behave differently in their GLOBE Science Notebooks.
9. Ask the students to explore how what they have learned from their experiment may be used in real life circumstances to understand what might occur in their local watershed and land use questions in their community. They might explore questions such as:
   - *What might happen if the soil in an area is tightly compacted and there is an extended heavy rain?*

Further Investigations

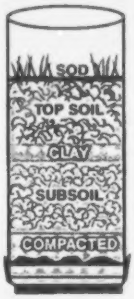
1. Challenge students to come up with strategies for building a soil column in a 2 liter clear, plastic bottle which will SLOW or SPEED UP the rate of water flow through a soil.

   Brainstorm ideas for accomplishing the task. Hint: soil may be sifted and the particle sizes layered. Students may also add clay, sand or mulch. Soils may be compacted. Have students record their method and measure and record the 'soil recipe' they use. Hint: The rate of flow may be very slow for loams or clayey soils. Teachers may want to have students build their soil column one day, then have a student come in before class the next day and start the water flow.

   Record the results for the rates of water flow. Which strategies worked best? Ask students to determine whether the same strategies work for moving water through the soil slowly and for holding water in the soil.

2. Build a soil column similar to the soil profile at one of your soil characterization sample sites (use the samples for each of the horizons in the same order they are found in the profile). Observe how the water-soil interaction occurs in a simulated profile.

Figure SOIL-L-3: Experimental Soil Column



More Advanced

Based on the observations and results of their experimentation, have students design experiments to test other hypotheses they may have developed. Some possible ideas include:

1. Have students hypothesize about how soil can affect other aspects of the chemistry of water. Take a reading of NPK using the Soil NPK kit with the soil alone, and with a water sample. Repeat the water measurement after it has passed through the soil.
2. Have students experiment with adding salt to the water and testing the conductivity or salinity of the water before and after it goes through the soil.
3. Add vinegar or baking soda to the water and test the pH and alkalinity before and after water is added to the soil.
4. Ask the students to hypothesize about the effect of evaporation on the amount of water the soil will hold. What are the factors that control evaporation? Use some soil of the same type in two bottles and saturate both with water. Leave one bottle open on top and cover the other bottle securely with plastic wrap or other cover. Place both in a sunny window. The weight of the soil in each of the bottles will be a function of how much water it holds over time. Students can graph the difference in weight over time for the covered and uncovered bottles.
5. Place a mulch or growing sod over the soil in the bottle. How does this affect the rate at which water infiltrates the soil? How does it affect the clarity of the water that comes out the bottom? How is this related to erosion in the real world?
6. Ask students what changes may occur if the soil remains saturated with water over long periods of time. Place a soil sample in a bottle which has not had the bottom removed, then saturate it. Can they detect changes in structure, color, smell? How long does it take for changes to take place?

Have students examine soil moisture data for five GLOBE sites which have approximately the same amount of precipitation over a six month period. Graph the monthly soil moisture for each site. How do the graphs differ? What other GLOBE data can students find that might explain the variation?

Student Assessment

Students should know the scientific method and how to use it to set up an experiment as well as understand the scientific content relating to soil moisture. They should also be able to demonstrate higher order thinking skills such as drawing conclusions from experimental observations and they should be able to justify their conclusions with evidence. These can be assessed by using a portfolio assessment of their GLOBE Science Notebooks, class participation in discussions and the contribution of questions, hypotheses, observations and conclusions. The quality of their presentations are another mechanism for assessing their progress. It is also a good idea to have the students prepare a written report or a paper on their experiment. The experimental work should be done in groups as should the presentations and the reports so that their ability to work cooperatively in groups can also be assessed.

Note: This activity works nicely when done in conjunction with the soil moisture protocol. The activity can begin in the classroom before going out to set up the sampling strategy or take a soil moisture measurement. Additional observations

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and recording of flow rate, volume of water, pH, water clarity, etc. can be taken when returning to the classroom. (For some soils, it may take some time before all the water flows through the soil columns.) The activity also places both the soil moisture and soil characterization protocols in a conceptual context for the students. They will understand why the information and data they collect are important for developing hypotheses, designing experiments to test the hypotheses, interpreting observations, and making conclusions. They will also develop an understanding of the potential research significance of the soil moisture and characterization data.

From Mud Pies to Bricks

Purpose

To introduce the different particle sizes of soils and the properties which each contributes to the soil character

Overview

Students will sift soil to remove organic materials and pebbles. They will then sift the soil with smaller meshed sieves to separate clay and sand. Students will make mud pies by adding water to the various soil components, letting them dry and observing the pie's characteristics. Finally, students will be challenged to create the perfect mud pie or building brick using combinations of soil components.

Time

One class period to sift soils and make mud pies

Overnight to dry

One class period to experiment with creating bricks

Overnight to dry

Level

All

Key Concepts

Soil is composed of a variety of materials.

The size of soil particles helps determine the soil characteristics.

Soil is important as a building material.

Skills

Sifting soil samples

Observing differences in particles

Measuring or *weighing* soil

Designing experiments

Testing results

Materials and Tools

1 liter soil (loam) for each student group

Several sizes of mesh screen or sieves for sifting

Straw (dried grass clippings)

Additional powdered clay and sand

Old ice cube trays (for brick molds)

Small plastic lids or plates (for pies)

Plastic table cloth

Prerequisites

None

Background

Soil is made up of many different size grains of broken-down rock (sand, silt and clay). How much water a soil will hold, how easily water passes through the soil, and what happens to the soil as it dries depends on the combination of these materials in your particular soil. Soil with too much clay may crack as it dries - you have probably seen pictures of ground with huge cracks or observed the cracking at the top of a mud puddle when larger, heavier particles have settled to the bottom. Soil with too much sand may not hold together well or be strong enough as a building material.

Soil has been used as a building material for thousands of years, and is still one of our most important building materials. In dry regions houses built of adobe bricks last hundreds of years. Concrete and bricks are common everywhere. Whether you are making concrete or adobe blocks, it is important to understand the importance of having the right elements in your soil mix.

What to Do and How to Do It

Observation

1. Ask students to examine the soil carefully using their eyes, hands, and a magnifying glass.

2. Make a list of the things students observe about the soil. For example: *different size, shape, and color of grains, other soil materials such as sticks or leaves, 'dustiness', weight, etc.*
3. Ask students if they think the soil would be different if all of the particles were alike or if some parts were missing. How would it be different?
4. Starting with the largest mesh sieves, sift the soil.
5. Place what does not go through the sieve in one pile - these are the largest particles.
6. Ask students to examine the 2 piles. How are they alike and different? Can they think of reasons why different size particles would be good for different things?
7. Take the soil that passed through the sieve and sift it through the next smaller mesh.
8. Keep what did not go through the sieve separate, and continue sifting through smaller mesh screens. Students will now have several piles of soil separated by the size of the particles.
9. Ask students to identify words that describe the different piles of soil they now have. Identify the concept of particle size: sand, silt and clay. Words might include: *powdery, rough, smooth, dusty, etc.*

Experimenting

1. Discuss with students the importance of soil as a building material. Ask students to identify things that are built with soil. Example: *concrete sidewalks, brick buildings*
2. Have students describe how they would make a brick using the soil they have.
3. Ask students to describe the characteristics of a good mud pie or brick. For example: *hardness, cracking, resistance to breaking or water, etc.*
4. Ask students to guess which pile of soil would make the best mud pie or brick. Why did they choose the pile of soil that they did? What will happen to each pile when water is added to it?
5. Have students make mud pies or bricks from the soil in each pile by adding water then molding by hand or putting into a mold like an old ice cube tray.
6. Dry completely in the sun or in a warm place.
7. Ask students to test the mud pies or bricks that they made for breaking, cracking, smoothness, etc.. List what is good or bad about each one.

More Challenging

1. Challenge students to create the perfect mud pie or brick by combining different amounts of the soil particles they sifted out. Additional sand, clay or organic material may be provided, especially if your original soil did not contain very much of one of these elements. Have students measure or weigh the different ingredients and write a 'recipe' so that they can compare with other students or recreate their creation.
2. Older students can figure the percent weight of each soil component in their recipe.

Further Investigations

1. What happens when the dried bricks get wet? Research how adobe houses are protected from rain.
2. Examine a piece of broken brick. What soil elements can you identify? Why are bricks water resistant?

Assessment

Have students observe soils around their school or at their biology site. Ask how they can determine areas which have more clay or more sand.

Recipe Card	amount
Ingredients:	
clay (smallest size particles)	
silt (medium size particles)	
sand (large size particles)	
other	
other	

Soil and My Backyard

Purpose

To explore soil and soil properties

Overview

Students will discover the variability of soils, derive relationships among soils and the soil forming factors, and link the GLOBE Soil Investigation to the students' local environment. Students use soil samples from their homes to identify properties that characterize their soils. They compare and contrast their soils to those of their classmates. As a class, students describe relationships between the properties of their soils and how and where they were sampled. Older students construct a soil classification schema.

Time

One class period to observe soil properties and one or two periods for discussion

If soils are to be dried and changes observed, an additional class period will be needed.

Level

All

Key Concepts

Soils vary within a small local area

Soil properties are related to the soil forming factors.

Soil can be classified according to its properties.

Skills

Sampling of soil

Classifying soil

Materials and Tools

Newspaper

1 liter plastic bags

Local map (topographic or road map which encompasses the school district)

Magnifying glass.

Preparation

On the day of the activity, prepare an area in the room for observing the soils. For example, cover lab tables with newspaper. If students will be drying their samples, you will need to identify a place where soils can be left undisturbed for several days. See the instructions for drying soils in The Soil Protocols – *How to Perform Your Soil Measurement*.

Prerequisites

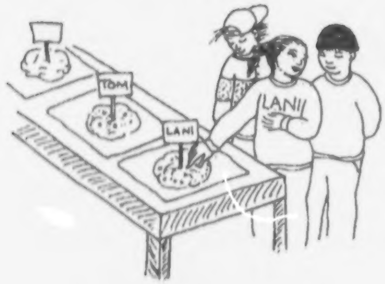
None

Background

Soils vary in their properties depending on where they have been sampled on a landscape and from what depth they were sampled. As your students examine their soils, help them to think about what they are observing by asking: What properties do you notice? Are the soils wet or dry? What colors do you see? Can you identify the components (organic material [both plant and animal], rock fragments, sand, clay, etc.) of your soils? How does the soil smell? How do the soils feel? How do dry soils differ from the original soil samples? Are there differences within a single soil sample? How does your sampling procedure effect what you see? How would you group or classify their soils?

What To Do and How To Do It

Before giving the student the homework assignment of collecting soil samples ask them to hypothesize how many different types of soils the individuals in the class can find in their



neighborhoods. They need to use previous experience or knowledge to answer the question.

Before Class

Have students bring soil samples from home, using 1 liter plastic bags. They should document their collection methods (such as noting the location from which each sample was taken, the depth of the soil, storage methods, etc.). For younger students you may want to establish a class protocol for sample collection – either through a brainstorming activity or by providing one.

During Class

In the classroom, students should spread out their soil samples and examine them closely. Record observations about the soil in their GLOBE Science Notebooks.

Have each student find one person in the class that has a soil similar to their own soil. Record how they determined that the soils were similar.

Have each student find one person in the class that has a soil that is different from their own soil. Record how they determined that the soils were different.

As a class, brainstorm and list on the board the different characteristics the students used to describe their soils. Ask the students to group characteristics that appear to belong together. Use words that describe these similarities, such as same color, same "feel," a number of roots. Have students describe how the observed soil properties relate to the soil forming factors.

Discuss what factors could lead to the different characteristics (five soil forming factors, sampling effects, etc.).

Ask the students to compare their observations with their hypotheses about how many types of soil they are likely to have represented in the class samples.

Ask them to discuss how their knowledge of the soil characteristics changed based on their investigations. What did they learn? Be specific listing such things as soil characteristics, how soil may vary in characteristics within a relatively small area, etc.

Adaptations for Younger and Older Students

Younger students should focus on making observations and comparisons.

Older students can perform more in-depth investigations in teams or as a class by:

Developing a standardized procedure for soil sampling and having your students bring in a second sample collected by following the class procedure. Compare each set of samples.

Developing a scheme to classify soils based on soil properties.

Drying the soil samples for different lengths of time and comparing physical differences between soil in various states of moisture.

Plotting on a local map sample collection sites and the distribution of the various soil classes.

Further Investigations

Find out where there is digging (excavation) going on nearby and visit the site, comparing what you observe there with the soil characteristics described in your backyards.

Remember: Safety is always your first concern.

Select another school in a part of the world known for certain characteristics (e.g. a rainy season, thick vegetation, etc.). Pick a school that has a history of submitting messages and/or data. Write a note to the students via GLOBEMail describing your soil and asking them to describe their soil to you. How do the differences in your climates (for example types of seasonal cycle, temperature ranges, amounts of precipitation, types of land cover) relate to the differences in your soils?

Compare your results with those of the other school and discuss any difference with your GLOBE colleagues at your school and the other school.

Investigate what kinds of soils make the best homes for earthworms or other soil-dwelling creatures.

Develop a scheme for grouping (classifying) soils based on soil properties.

Student Assessment

Give students samples of a mystery soil. Depending on their age, they could:

Describe the soil in their GLOBE Science Notebooks, using as many adjectives as possible and covering as many soil characteristics outlined in the Soil Characterization Information Sheet as can be observed.

Consider the implications of the characteristics for its possible history and location.

A Field View of Soil - Digging Around

Purpose

To understand that variations in the landscape can affect soil properties

Overview

Students will investigate variations in the soils around their school to discover that soil properties like moisture and temperature exhibit considerable variability across a single landscape. They will be able to identify factors such as slope, shade, plants, compaction, which affect the appearance of soils and their ability to hold moisture.

Time

Two class periods: the first for the field trip; the second to discuss findings and causal connections

Level

All

Key Concepts

Soil profiles can be described based on the five soil-forming factors.

Soils within a small geographic area can show considerable variety.

Soil factors also affect soil moisture content and temperature.

Skills

Observing and *describing* soil samples

Collecting data in the field

Identifying relationships between the soil-forming factors and the resulting soils

Materials and Tools

Small shovel or trowel

GLOBE Science Notebooks

Prerequisites

None

Background

Factors Affecting Soil Properties

Every soil is unique on every place on Earth. What makes each soil unique is the way the five soil forming factors work together at any particular place. As you look around your site, notice if the effects of the five soil-forming factors are different on one part of the site than another.

Some properties that you may notice that change from one soil to the other are :

- the color
- the kind and amount of vegetation on the soil surface
- the amount of roots in the soil surface
- the shape of the soil particles when you look at them (called the soil structure)
- the way the soil feels (called the soil texture)
- the amount and size of rocks in the soil
- number of worms or other animals in the soil
- how warm or cool, wet or dry the soil feels. (Wet soil will be sticky and clump together, moist soil will feel wet and cool, and dry soil will feel like it has no water in it.)

Factors Affecting Soil Moisture

Because each soil is unique, each soil will also hold a unique amount of water. The amount of water held in the soil may depend on many things. Among these are the speed at which precipitation (rainfall, snowfall, sleet, etc.) enters (infiltrates) the soil or runs off, the temperature, and the plants. If soil is tightly compacted, as on a well-trodden path, the water will not be able to enter the ground as easily as in less traveled areas. Nature may increase runoff in some areas. For example, in dry climates, "desert pavement" (small rocks laid tightly across the sand like a tile floor) may increase the amount of runoff.

Wind and water may help to form crusts on some soils that prevent the infiltration of water. Slope also increases the speed at which water runs off the land. Rain will quickly disappear on a steep slope, but collect in puddles on the flat ground. The roots of plants help to break up the soil, creating a *porous* medium in which water can pass. Sandy soils usually let water in faster than clay soils.

You might think that there is little variation of temperatures on your site. However, there may be quite a bit of difference from one place to another. Shade makes cooler temperatures. Shade is not found just under trees. It may be cooler in the shade under a rock or on the side of a rock away from the sunlight. The soil may be drier in warm places, and wetter in cool, shady places.

Plants may also affect soil moisture. They may provide shade. They also use water.

What To Do and How To Do It

Begin by Asking:

1. In your part of the world, which side of a slope gets the most sunlight - the north or the south?
2. If you were going to hunt for fishing worms (or other soil dwelling invertebrates), where would you look? Why would you look there? Remember, animals need water, air and nutrients, which are found in various soils. In compacted soils, it is more difficult for animals to survive.
3. Do more types of plants seem to grow on slopes or in valleys? Why?

At the Study Site

1. Divide the class into groups of 3 to 5 students. Each group should have a small shovel or trowel, and their GLOBE Science Notebooks.
2. Have groups look for differences in soil properties at different places in the site by digging up a small amount of soil, looking at it, and feeling it. Have them record what they find in their GLOBE Science Notebooks.

The Five Soil-Forming Factors

Climate: Is one part more shaded or sunnier, cooler or warmer, drier or wetter? How would the temperature and moisture be different in a sandy soil than in a clayey soil? How would this affect the way plants grow?

Topography: Are there different slopes on different parts of the site? Where is it flat on the site? Are there areas that rise up or slope down? What are the different types of positions on the landscape (high spots, middle of the slope, low areas)? Where are the highest places; the lowest?

Plants and animals: How do the types of vegetation change on the site? Can you see evidence of animal life? What kind of insects are present? How is the site used by humans? (such as: is it a park, a field, a lawn, a forest, a plantation, an urban area).

Parent material: From what kind of material was your site formed? Do you see rocks at the surface that can give you an indication? Are these rocks near a stream so that they may have been deposited by water? Could they have been deposited by wind (such as a sand dune), or by gravity down a hill, or by a glacier, or by a volcano? (You may need to do some research to determine the geology of your area).

Time: How long has this site been undisturbed? Is there a lot of organic material on the soil surface? Are there grasses, trees, crops, or other plants that have been growing for a long time without being disturbed? Has there been recent building or construction? If it is a field, has it been recently plowed? Have trees been removed from the site? Has there been a recent flood or other natural disturbance that may have affected the formation of the soil?

Ask them to note types of plants, presence of rocks, roots, and soil animals (such as earthworms), how hard or easy it is to dig, distances to items on the landscape or other things they notice. See the box, the Five Soil-Forming Factors, for guiding questions. Have students list the areas they investigated from the wettest to the driest. Note how the moisture content is affected by the location, the type of plant cover, the position, or other things at the site.

Extensions

1. Have students make a sketch map of soil characteristics on their site.
2. Have students "landscape" their site. If this site was going to become someone's yard, where would you plant things?

Student Assessment

Ask Students:

1. In which parts of the site would you expect soils to be most alike? Consider regions with similar soil forming factors.
2. Where would you locate the soil that is the most typical for your area? Look for large areas within your site which have common characteristics.
3. What things on the landscape affect soil-moisture?
4. What things should you consider when choosing your soil-moisture site in your area?

Soils as Sponges: How Much Water Does Soil Hold?

Purpose

To introduce students to "gravimetric measurements" – calculating the amount of water in a soil sample or other substance by weighing it before and after drying

Overview

Students will weigh a wet sponge, squeeze it to remove water and weigh the dry sponge. This helps students understand that objects can hold water and that the amount can be measured. Students then transfer this concept to soil, weighing wet and dry soil samples, and then apply this wet/dry comparison to other objects, such as leaves and fruit.

Time

Approximately two class periods for the initial sponge and soil activities; then 10-15 minutes per day for about 3 days, as objects dry

Level

Intermediate and advanced

Key Concepts

Different objects can hold different amounts of water.

When objects dry, they release their water.

Squeezing and evaporation are two ways to remove water.

Soil water content is a measure of the amount of water in a soil sample.

Soil water content varies around the world.

Skills

Measuring the weight of wet and dry objects

Comparing the water-holding capacity of different objects

Observing changes in weight over time as an object dries

Calculating the amount of water in soil samples and other objects

Estimating the moisture levels in a variety of objects

Comparing soil water content around the world with GLOBE visualizations

Materials and Tools

Scale or balance

Several sponges

Paper towels

Graph paper (for intermediate or advanced)

Soil samples

Other objects to dry (such as fruit, leaves, vegetables)

Prerequisites

Knowledge of fractions and decimals

Background

Many objects hold water. For living beings, this water is essential for survival. In the case of soil, this water is essential for the survival of the plants and animals that live or grow in the soil. In fact, soil moisture is one of the best predictors of what will grow in an area. This is why Dr. Washburne and Dr. Levine need soil moisture data in their research.

One way to calculate soil moisture is to make a gravimetric measurement. Gravimetric means to find the weight, or the pull of gravity, upon an object. When calculating soil water content, we want to find the weight of the water contained in the soil. To do this we measure the weight of a soil sample, dry it out, and then measure the weight of the dried soil. The difference in the weights is the amount of water originally in the sample. We then normalize by dividing by the dry sample weight.

For example, you might dig up a handful of soil and find that it weighs 100 grams. After the soil has dried, you weigh it again and find that it only weighs 90 grams. Ten grams of water have evaporated from the soil, but this must be normalized, to remove sample size bias, by the weight of the dry soil (90 - 30 = 60 g assuming a 30 g can weight). We can calculate the fraction 10/60=0.167. This is a measure of how much water is in the soil (water content). Since we are using a balance, which depends upon gravity, this is called the gravimetric water content.

Soil water content calculations are simple to do, as long as you care for samples properly and measure accurately. When the air is dry, evaporation can happen quite rapidly. Think how fast you dry off after getting out of the pool on a hot, dry day. Soil samples will dry quickly in the air, too, if they are not placed in a sealed container as soon as they are dug up.

Soil moisture is influenced by many environmental factors, such as temperature, precipitation and soil type, as well as topographic features, such as slope and elevation. Soil moisture is especially important for agriculture. Much of the hard work of farming, such as plowing and discing, is done to try to improve the soil-moisture related properties of the soil. Terracing (making ridges in a field) is done in some areas to prevent too much runoff, while fields are rounded in other places to keep the soil from staying too wet. Further, different crops require different amounts of water throughout their growing season. Understanding how the soil moisture changes through the year can help a farmer decide what to plant.

In this activity, students measure the moisture in several objects, before and after drying. They do these experiments in five stages of increasing difficulty:

Stage 1 – Squeezing water from sponges

Students weigh a wet sponge, squeeze it, then weigh the dry sponge and the water that was squeezed from the sponge. Doing this, they see that, in essence: wet sponge = dry sponge + water. Squeezing is a very visible and immediate way to release water.

Stage 2 – Evaporating water fom sponges

Students do the same exercise as above, except that they let the sponge sit for several hours or a day to let the water evaporate. When they weigh the dry sponge, they should get approximately the same weight as in stage 1 (although evaporation may have removed more water than the squeezing did).

Stage 3 – Measuring soil moisture

Now students transfer the concept of evaporative drying to soil by letting soil samples dry for a day or two. They measure the weight before and after to measure the soil moisture. They compare several soil samples to get a sense of a typical range of values.

Stage 4 – Removing water fom other objects

Students transfer this understanding of measuring soil moisture to determine the moisture of other objects, such as fruit or leaves. They experiment with different ways to dry the objects: fans, squeezing, sunlight, salt, etc. They also estimate the wetness values.

Stage 5 – Using GLOBE visualizations for worldwide soil moisture

Students use the GLOBE visualizations on the Worldwide Web to study a map showing soil moisture in other parts of the world. They discuss why there are differences, and conduct further investigations based on student interest in the topic and the visualizations.

At this time, GLOBE lacks sufficient soil moisture data to produce visualizations. As soon as enough data are available, visualizations will be produced and made available over the Web.

What To Do and How To Do It

Preliminary Exercise

If your students do not know how to use the scale or balance, you should teach them how and let them practice weighing objects.

Stage 1 – Squeezing water from sponges

1. Soak a sponge in water. Weigh it and record the wet weight. Ask your students how much they think it will weigh when it is dry. Record the estimates.
2. Squeeze the sponge and weigh it. Record the dry weight. Discuss with students how their estimates compared with the actual value.

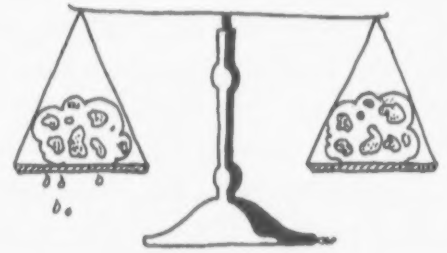
3. Ask your students how much water was in the sponge. See if they can figure out how to calculate this. This amount of water = wet weight of sponge minus the dry weight of sponge. For example, 120 grams of water = 200 gram wet weight minus 80 grams dry weight.
4. Now repeat the measurements with a different sponge. Have your students figure out which sponge can hold the most water.
5. You now have an absolute measure of the water content. Next find the relative measure of water by dividing by the dry sponge weight.
6. To extend this activity, for each sponge you can collect the squeezed out water in a plastic cup, and then weigh the water (make sure you deduct the weight of the cup to get the weight of the water itself). The actual weight of the water should be the same as the calculated weight.
7. In your discussion with your students, make sure they understand the concept of water-holding capacity, and that this differs from one type of sponge to another.

Stage 2 – Evaporating water from sponges

1. Ask your students what will happen if you leave the wet sponge on a tray overnight instead of squeezing it. If your students understand the concept of evaporation, you can discuss that with them. Otherwise, wait until later in this activity to discuss evaporation.
2. Have your students weigh the wet sponge, record the weight, and leave the sponge on a tray, preferably in sunlight. Leave it exposed until the next day.
3. After the sponge has been left out for a day, have your students weigh the dry sponge (it should be dry by now).
4. Ask your students where the water went. Older students who understand evaporation will know the answer. Otherwise explain evaporation to your students.
5. Calculate how much water left the sponge to find out its water-holding capacity. This figure may be different from what they measured when they squeezed the sponge. Ask them why the numbers are close (because both squeezing and evaporating removed most of the water), and then ask them why the numbers are not exactly the same (because evaporation removes more than squeezing, although it takes longer).
6. Ask your students why a high water-holding capacity is important for a sponge, and what other objects might need a high water-holding capacity.

Homework

Explain to your students that they will soon be measuring how much water soil can hold. Ask them to bring in a soil sample from home. They should put the soil sample into a small plastic sandwich bag, then seal the bag to retain its moisture.



Stage 3 — Measuring the moisture of soil

1. Have your students put their soil samples (still in the tightly-sealed plastic bags) on their desks or tables. Ask them how they might measure the wetness of the soil. In their answers, the central concept to look for is to weigh the wet soil, dry it (there are many ways to dry it), and weigh it again, just as they did with the sponge.
2. Have each student or group of students open their sealed baggy, weigh the wet soil, and set it aside to dry. Drying may take a day or two.
3. When the soil is dry (have them touch the soil to feel how dry it is), have your students weigh each soil sample again. Ask them how much water evaporated.

4. Introduce the formula for soil water content. Soil water content =

$$\left(\frac{\text{Wet Weight - Dry Weight}}{\text{Dry Weight - Can Weight}}\right) 100$$

This is the formula used in the soil moisture protocol. For example, if the wet weight is 100 grams and the dry weight is 90 grams, and the can weight is 30 grams then the soil water content will be

$$\frac{100 \text{ g} - 90 \text{ g}}{90 \text{ g} - 30 \text{ g}} = \frac{10}{60} = .167$$

$$100 \times .167 = 16.7$$

5. Have your students calculate the water content of their soil and compare the values. Correct any errors in their calculations. Discuss the range of values and why they think there is such variety. Have them examine the different soils to help them think about why there is such a range.

Intermediate and Advanced Students

In the above activities, older students can weigh the soil every hour, and then graph the results to see whether water evaporates at a constant rate or the evaporation rate changes, such as slowing the closer the soil gets to being dry, or evaporating more quickly when the sun is shining on it. You might also link the discussion with weather factors, such as how quickly the soil might dry on very dry or humid days.

Homework

Explain to your students that they will be drying other objects. Ask them to bring to class some fruits, vegetables, leaves, rocks or anything else they are interested in experimenting with.

Stage 4 — Removing Water From Other Objects

1. Have your students show and discuss the objects that they brought in to dry. Have them estimate the water content for each object. Record their estimates, either as individual estimates or as class estimates.
2. Have your students weigh each object and record its wet weight.
3. Brainstorm with your students for ways to dry the objects. Previously they squeezed and evaporated water. What other ways are there? How could they speed up or slow down the process? Some ideas are: put the objects in direct sunlight; blow a fan over them; put them on a heater; put them in a microwave or oven; pour salt on them; cover them with a plastic container; point a light on them.
4. Select among the techniques and see the results. The more time you have available, the more your students can experiment.
5. After one or a few days, when the objects are dry, have your students weigh them again. Then have them calculate the wetness of each object. Compare the actual values with their estimates. Which results surprised them?

Stage 5 — Using GLOBE Visualizations for worldwide soil moisture

Intermediate and Advanced Students

Note: Perform this stage once sufficient data have been submitted to GLOBE for visualizations and the visualizations are available on the GLOBE Student Data Server.

This activity is appropriate for intermediate and advanced students who have the requisite map-reading skills and basic understanding of soil moisture issues. Do this activity after your students have begun submitting soil moisture data based on the GLOBE soil protocols.

1. Use the GLOBE Web page to access and display a map showing soil water content around the world based on the most recent student measurements. This is an exciting opportunity for your students because soil moisture data from all over the world have never before been available. Dr. Washburne and Dr. Levine are using the same data for their research.
2. You can display the soil water content data either as values or as contours (with different colored bands corresponding to certain ranges of soil moisture values).

3. Make sure your students make the connection between their own soil water content measurements and the soil water content readings from other schools around the world.
4. There are many domains of investigation for your students. Here are some examples:
    - what is the range of soil water content values around the world?
    - where is it the lowest? the highest?
    - does this vary over time? (examine soil water content maps from other months)
    - what affects the soil water content of the different sites?
    - do soil water content values depend on recent weather conditions?
    - compare readings from a desert, a rain forest and a farming area
    - what areas have about the same level of soil water content as your site?
5. Encourage your students to pursue further investigations using the GLOBE soil water content visualizations.

Student Assessment

Bring a set of soil samples to school. Have your students estimate the soil water content. Have them calculate the soil water content (do not remind them how). Check for reasonableness in their estimates, and watch the process to make sure they do it correctly.

Soil: The Great Decomposer

Purpose

To introduce students to the role that soil, under different environmental conditions, plays in the decomposition of organic materials

Overview

Students will simulate a variety of environmental conditions to determine which conditions facilitate the decomposition of organic material in soil. Variables will include temperature, moisture, and light conditions. Students will use "bottle" experiments to observe changes in the decomposition of vegetable scraps.

Time

One class period to discuss and plan experiment, one class period to set up experiment, part of class period at daily (or every other day) intervals to record results, and one class period 2 weeks later to observe and discuss final results. Additional time may be desired to perform further investigations.

Level

All

Key Concepts

Decomposition in soil depends upon different environmental conditions.

Skills

Conducting an experiment
Observing
Predicting outcomes

Materials and Tools

12 glass jars or beakers or 2-liter plastic bottles (more for additional studies)
Marking pen or labels
Enough dry soil to add 10 cm to each jar. Use the same soil (loam or potting soil) for each jar.
Enough chopped vegetable or fruit scraps (carrots, cucumbers, apples, etc.) to add two to three cm to each jar (use the same fruit or vegetable scrap mixture in all jars). Other sources of organic material include leaves (broken up), grass clippings, flowers, etc. *Do not use animal scraps.*
Graduated cylinder or measuring cup to add specific amount of water to soil
For further studies:
Earthworms (collect from local soil)
Soils with sandy and clayey textures

Preparation

Have the soils, bottles, and vegetable scraps available. Ask students to bring in vegetable scraps on the day of the experiment.

Locate areas in the classroom that will provide variable conditions required for the experiment (warm, sunny site; cool, sunny site; warm, shaded site; cool, shaded site).

Prerequisites

None

Background

Light, temperature and water content largely determine the rate of decomposition in the soil. Soil holds the moisture and heat required for microorganisms to thrive and perform the decomposition process, changing organic materials into soil material called humus.

Soils have different abilities to hold moisture, heat, and to support organisms. If the soil is too wet, too dry, or too cold, decomposition will be slow. Energy from the sun will warm the soil and also promote evaporation, which will affect the moisture content in the soil. Students will be asked to investigate what conditions contribute to rapid decomposition of organic material in soil.

What To Do and How To Do It

Set out 12 jars or beakers on table. Label each as follows:

1. Dry, warm, sunny
2. Moist, warm, sunny
3. Wet, warm, sunny
4. Dry, warm, shady
5. Moist, warm, shady
6. Wet, warm, shady
7. Dry, cool, sunny
8. Moist, cool, sunny
9. Wet, cool, sunny
10. Dry, cool, shady
11. Moist, cool, shady
12. Wet, cool, shady

Add equal amounts of soil (about 10 cm) to each jar.

Add equal amounts (about 2-3 cm) of vegetable material to each jar and evenly mix the soil and vegetable material. Use the same type of vegetable material in all jars.

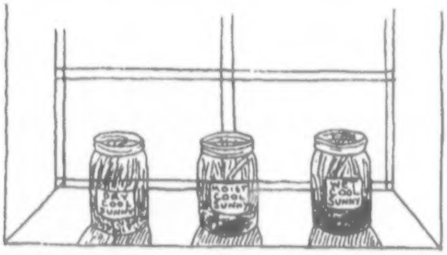
In each of the 4 jars marked "wet," saturate the mixture with water (allow water to cover the surface of the soil).

In each of the 4 jars marked "moist," moisten the mixture with water.

Leave the mixture to dry in the 4 jars marked "dry."

Place one wet, one moist and one dry jar in a warm place that is shaded (as marked).

Place one wet, one moist and one dry jar in a warm place that also gets sun for part of the day (as marked).



Place one wet, one moist and one dry jar in a shaded, cool place.

Place one wet, one moist and one dry jar in a cool place that also gets sun for part of the day (as marked).

Cover the jars but poke small holes in the top for air to circulate.

Every other day, saturate soils in jars that are marked "wet," and moisten soils in jars marked "moist." At this time, stir the soil/vegetation mixture in each jar.

For a period of two weeks, observe the jars daily (or every other day) and record observations. Note changes in water content and the condition of organic matter.

Discuss with the class how light, temperature, and water content affected the amount of organic material left in the soil after 2 weeks. Which jars (conditions) show the most decomposition? Which jars show the least decomposition? Can you rank the jars from the least to most decomposition after 2 weeks?

Once students have discussed their observations, have them design their own optimal decomposer using any combination of the variables in the investigation. Have them justify their choice of conditions and predict how each factor will contribute to decomposition.

Adaptations for Younger and Older Students

For Younger Students

Reduce the number of jars to either:

1. moist, wet, and dry (same temperature and light conditions), or
2. moist, warm and moist, cool (same light conditions).

Talk about which climates across the globe would have these conditions, and compare them to the climate in your local area.

For Older Students

Discuss and relate how decomposition of organic material varies across the globe. What are the sources of organic material in different areas? How does climate affect how fast the organic material will become humus? Have them speculate on what climate conditions will promote the decomposition of organic material and what will inhibit the decomposition of organic material? How would decomposition in a tropical soil differ from that in a northern forest?

Further Investigations

Using soils with "optimal conditions", place earthworms in one jar and leave a second jar earthworm-free. Observe and record earthworm activity, rate of decomposition, and differences in soil properties after 2 weeks between each jar. You may also want to create a "worm farm" in a glass jar to observe worm behavior, decomposition, and changes in soil over a longer period of time.

Do a similar experiment as above but vary the soil texture. Include jars with sandy soil and clayey soil and observe differences as above.

Ask students to research composting.

Making Sense of the Particle Size Distribution Measurements

Purpose

To understand the theory behind the *Particle Size Distribution Measurements* Protocol and how the data can be used to predict percent sand, silt, and clay

Overview

Using the measurements made in the *Particle Size Distribution Measurements Protocol*, the amount of sand, silt, and clay in grams and in percent will be calculated. Students will also be introduced to the theory behind the settling experiment (Stoke's Law), and instructed on how to use the textural triangle with both the results from their measurements and a sample set of sand, silt, and clay measurements for practice.

Time

One class period

Level

Intermediate and Advanced

Key Concepts

How different particle sizes in the soil are distributed to create a specific texture

Stoke's Law and particle settling

Skills

Reading a conversion table

Using mathematics to correct hydrometer readings for volume and temperature

Calculating the amount of sand, silt and clay in grams and in percent of the sample

Reading information from a textural triangle

Estimating percentages

Materials and Tools

Data from Soil Particle Size Distribution Measurements Data Work Sheet

Copy of the textural triangle for each student

Ruler or straight edge

Preparation

Conduct a discussion of different size particles in soils and their distribution. See the Introduction.

Perform the *Particle Size Distribution Measurements Protocol* to obtain the measurements required for this exercise.

Background

The amount of each size particle (sand, silt, or clay) in the soil is called the particle size distribution. Knowing the particle size distribution of a soil sample helps us understand many soil properties including how much water, heat, and nutrients the soil will hold, how fast water and heat will move through the soil, and what kind of structure and consistence will form. Sand, silt, and clay are the 3 particle sizes of mineral material found in soils. The amount of each of these is called the particle size distribution and the way they feel is called the soil texture.

Sand is the largest sized particle, silt is medium sized, and clay is the smallest. There is disagreement in the scientific community about the exact size ranges of sand and silt. For GLOBE, we will measure sand and silt based on 2 different size definitions:

1. The US Department of Agriculture (USDA) which defines the size of sand as 2.0 mm - 0.05 mm, and the size of silt as 0.05 - 0.002 mm.
2. The International Soil Science Society (ISSS) which defines the size of sand as 2.0 mm - 0.02 mm, and the size of silt as 0.02 - 0.002 mm.

Clays are the smallest particles and are defined (by both organizations) as being smaller than 0.002 mm. Particles greater than 2 mm are called stones or gravels and are not considered to be soil material.

Heavy, large particles settle first, so when a soil sample is stirred or shaken in a 500 mL cylinder, sand particles (according to the USDA definition) settle to the bottom of the cylinder after 2 minutes, while the clay and silt size particles stay in suspension. After 12 minutes, the sand, according to the ISSS definition, has settled, leaving the clay and silt size particles in suspension. After 24 hours, the silt size particles have settled, and only the clay stays in suspension to be recorded by the hydrometer.

To Determine the Amount of Sand, Silt, and Clay in Your Soil Sample

The specific gravity hydrometer is an instrument used to measure the density of water which has materials suspended in it compared with pure water. A hydrometer and temperature reading is made at 2 minutes, 12 minutes, and 24 hours during the *Particle Size Distribution Protocol*. To determine the amount of sand, silt, and clay in your sample, we will take each hydrometer reading and make a temperature correction to it. Next, we will use a conversion table (below) to convert the corrected specific gravity of the water to grams of suspended soil per liter (1000 mL) which includes a correction for the density of the dispersing agent that was added. Once we make that conversion, we need to multiply by the number of liters (0.5 L or 500 mL), in order to determine the number of grams of soil in suspension.

Obtain the data recorded on the Particle Size Distribution Measurements Data Work Sheet, and use the Calculation Work Sheet below to perform the following corrections:

1. Begin with your 2 minute hydrometer reading. From the conversion table below, determine the value of grams of soil/liter. At 2 minutes, this value corresponds to the grams of silt (USDA size) plus clay in suspension. All of the sand (USDA size) has settled to the bottom of the cylinder.
2. Note the temperature values you obtained 2 minutes. For every degree of temperature above 20 °C, add 0.36 grams to the grams of soil you obtained from the table. Subtract 0.36 for every degree below 20 °C.
3. Next, multiply the value for temperature-corrected grams of soil/L by 0.5 L to find out how many grams of soil we have in suspension in the 500 mL cylinders. This answer gives you the grams of silt plus clay in your sample.
4. Repeat procedure 1, 2, and 3 for the 12 minute and 24 hour hydrometer readings using the temperature read at each time period to correct for every degree above or below 20 °C. The 12 minute reading corresponds to the amount of silt (ISSS size) plus clay that is in your sample (the ISSS sand has settled at 12 minutes). The 24 hour reading represents the amount of clay in your sample (all of silt and sand has settled by 24 hours).
5. To find out how many grams of sand (according to the USDA) you have in your sample, subtract the amount of silt plus clay you calculated in step 3 above by the original amount of soil you used in the GLOBE Particle Size Distribution Protocol (25 grams). The percent sand is equal to the grams of sand in the sample divided by 25 grams (the original amount of soil), and multiplied by 100 to get percent.
6. To calculate how many grams and the percent of sand (according to the ISSS), repeat step 5 for the grams of silt plus clay you obtained at 12 minutes.

7. The grams of clay in your sample is the amount of clay determined above from the corrected reading at 24 hours. Dividing the grams of clay by the original weight of the sample used (25 grams) will give the percent of clay in the sample.
8. The amount of silt can be calculated by adding the grams of clay (step 7) and sand (step 5 for USDA or step 6 for ISSS) together, and subtracting that amount from the weight of soil added to the cylinder (25 grams). The percent silt is determined by dividing the grams of silt by 25 grams, or by subtracting the sum of the percent sand plus percent clay from 100 percent.
9. Repeat these calculations for the samples from each horizon in your soil profile. Use the Calculation Work Sheet to help your work. You can compare your results with the final results that will be returned to you after you submit the raw data from your Particle Size Distribution Measurements Data Work Sheet to the GLOBE Student Data Server.
10. You can use the Textural Triangle procedure to determine the texture name of your sample that corresponds with the particle size distribution.

Table SOIL-L-1: Conversion Table (specific Gravity to Grams of Soil/L)

Specific Gravity	Grams Soil/L
1.0024	0.0
1.0027	0.5
1.0030	1.0
1.0033	1.5
1.0036	2.0
1.0040	2.5
1.0043	3.0
1.0046	3.5
1.0049	4.0
1.0052	4.5
1.0055	5.0
1.0058	5.5
1.0061	6.0
1.0064	6.5
1.0067	7.0
1.0071	7.5
1.0074	8.0
1.0077	8.5
1.0080	9.0
1.0083	9.5
1.0086	10.0
1.0089	10.5
1.0092	11.0
1.0095	11.5
1.0098	12.0
1.0102	12.5
1.0105	13.0
1.0108	13.5
1.0111	14.0
1.0114	14.5
1.0117	15.0
1.0120	15.5
1.0123	16.0
1.0126	16.5
1.0129	17.0
1.0133	17.5
1.0136	18.0
1.0139	18.5
1.0142	19.0
1.0145	19.5
1.0148	20.0
1.0151	20.5
1.0154	21.0
1.0157	21.5
1.0160	22.0
1.0164	22.5
1.0167	23.0
1.0170	23.5
1.0173	24.0
1.0176	24.5
1.0179	25.0
1.0182	25.5
1.0185	26.0
1.0188	26.5
1.0191	27.0
1.0195	27.5
1.0198	28.0
1.0201	28.5
1.0204	29.0
1.0207	29.5
1.0210	30.0
1.0213	30.5
1.0216	31.0
1.0219	31.5
1.0222	32.0
1.0226	32.5
1.0229	33.0
1.0232	33.5
1.0235	34.0
1.0238	34.5
1.0241	35.0
1.0244	35.5
1.0247	36.0
1.0250	36.5
1.0253	37.0
1.0257	37.5
1.0260	38.0
1.0263	38.5
1.0266	39.0
1.0269	39.5
1.0272	40.0
1.0275	40.5
1.0278	41.0
1.0281	41.5
1.0284	42.0
1.0288	42.5
1.0291	43.0
1.0294	43.5
1.0297	44.0
1.0300	44.5
1.0303	45.0
1.0306	45.5
1.0309	46.0
1.0312	46.5
1.0315	47.0
1.0319	47.5
1.0322	48.0
1.0325	48.5
1.0328	49.0
1.0331	49.5
1.0334	50.0
1.0337	50.5
1.0340	51.0
1.0343	51.5
1.0346	52.0
1.0350	52.5
1.0353	53.0
1.0356	53.5
1.0359	54.0
1.0362	54.5
1.0365	55.0

Calculation Work Sheet

A. 2 minute hydrometer reading__________

B. temperature at 2 minutes ___________°C

C. grams/L of soil (USDA silt + clay) from table___________g/L

D. temperature correction[(0.36 x (B - 20° C)] _______g

E. corrected silt (USDA) and clay in suspension (C+D)______g

F. grams of soil (USDA silt + clay) in 500 mL (E x 0.5)_________g

G. grams of sand (USDA) (25 g - F)_______g

H. percent sand (USDA definition) [(G/25) x 100] __________%

I. 12 minute hydrometer reading__________

J. temperature at 12 minutes ___________°C

K. grams/L of soil (ISSS silt + clay) from table___________g/L

L. temperature correction [(0.36 x (J - 20° C)] _______g

M. corrected silt (ISSS) and clay in suspension (K+L)______g

N. grams of soil (ISSS silt + clay) in 500 mL (M x 0.5)_________g

O. grams of sand (ISSS) (25 g - N)_______g

P. percent sand (ISSS definition) [(O/25) x 100]_________%

Q. specific gravity at 24 hours_________

R. temperature at 24 hours ___________°C

S. grams/L of soil (clay) from table___________g/L

T. temperature correction [(0.36 x (R - 20°C)]_______g

U. corrected clay in suspension (S+T)______g

V. grams of soil (clay) in 500 mL (U x 0.5)_________g

W. percent clay [(V/25) x 100] _________%

X. grams of silt (USDA) [25 - (G + V)] ________g silt (USDA)

Y. percent silt (USDA) [(X/25) x 100]________%

Z. grams of silt (ISSS) [25 - (O+V)] ________g silt (ISSS)

AA. percent silt (ISSS) [(Z/25) x 100]________%

Example

Suppose the following were recorded from the 2 minute, 12 minute and 24 hour hydrometer readings:

	Specific Gravity	Temperature
2 minutes:	1.0125	21.0
12 minutes	1.0106	21.5
24 hours	1.0089	19.5

For each hydrometer reading of specific gravity, convert to grams/liter of soil from the conversion table, and correct for temperature.

For the 2 minute reading

The specific gravity reading is closest to 1.0126, which equals 16.5 grams of silt (USDA) and clay per liter in suspension. This value is then corrected for temperature. Since the temperature reading was 1 degree higher than 20°C, add 0.36 to the 16.5 grams/liter:

16.5 + 0.36 = 16.86 g/L

Next, multiply 16.86 g/L by 0.5 L (which was the volume of water used in the protocol) to change from grams/liter to grams:

16.86 x 0.5 = 8.43 which can be rounded to 8.4 g

This is the amount of silt (USDA) and clay in suspension.

To determine the amount of USDA sand, subtract 8.4 g from the original amount of soil added in the Protocol (25.0 g):

25.0 g - 8.4 g = 16.6 g of sand (USDA)

To calculate the percent of sand in the sample, divide 14.1 g by the original amount of soil added in the Protocol (25.0 g) and multiply by 100 to get percent:

(16.6 g/25.0 g) x 100 = 66.4% sand (USDA)

For the 12 minute reading

The specific gravity reading is closest to 1.0105, which equals 13.0 grams of silt (ISSS) and clay per liter in suspension. This value is then corrected for temperature. Since the temperature reading was 1.5 degrees higher than 20°C, add 0.36 x 1.5 to the 13.0 grams/liter:

0.36 x 1.5 = 0.54

13.0 + 0.54 = 13.54 g/L

Next, multiply 13.54 g/L by 0.5 L (which was the volume of water used in the protocol) to change from grams/liter to grams:

13.54 x 0.5 = 6.77 which can be rounded to 6.8 g

This is the amount of silt (ISSS) and clay in suspension.

To determine the amount of ISSS sand, subtract 6.8 g from the original amount of soil added in the Protocol (25.0 g):

25.0g - 6.8g = 18.2 g of sand (ISSS)

To calculate the percent of sand in the sample, divide 18.2 g by the original amount of soil added in the Protocol (25.0 g) and multiply by 100 to get percent:

(18.2 g/25.0 g) x 100 = 72.8% sand (ISSS)

Note: The amount of ISSS sand is greater than the USDA sand because ISSS considers sand to contain more fine particles, which USDA would classify as silt.

For the 24 hour reading

The specific gravity reading was 1.0089, which can be read directly off the chart as 10.5 g/L. This value represents the amount of clay per liter in suspension. The 10.5 g/L is then corrected for temperature. Since the temperature reading was 0.5 degrees lower than 20°C, subtract 0.36 x 0.5 from the 10.5 grams/liter:

0.36 x 0.5 = 0.18

10.5 - 0.18 = 10.32 g/L

Next, multiply 10.32 g/L by 0.5 L (which was the volume of water used in the protocol) to change from grams/liter to grams:

10.32 x 0.5 = 5.16 which can be rounded to 5.2 g

5.2g is the amount of clay that was in the original 25 g of soil used in the Protocol.

To calculate the percent of clay in the sample, divide 5.2 g by the original amount of soil added in the Protocol (25.0 g):

(5.2 g/25.0 g) x 100 = 20.8% clay

The amount of silt (USDA) is calculated by adding the grams of sand (USDA) to the grams of clay, and subtracting that sum from the original amount of sample (25 g):

16.6 g (USDA sand) + 5.2 g (clay) = 21.8

25g - 21.8 g = 3.2 g silt (USDA)

which can be converted to percent by dividing by 25:

(3.2/25) x 100 = 12.8% silt (USDA)

The amount of silt (ISSS) is calculated by adding the grams of sand (ISSS) to the grams of clay, and subtracting that sum from the original amount of sample (25 g):

18.2 g (ISSS sand) + 5.2 g (clay) = 23.4 g

25g - 23.4 g = 1.6 g silt (ISSS)

which can be converted to percent by dividing by 25:

(1.6/25) x 100 = 6.4% silt (ISSS)

For this sample, the final result would be:

	%Sand	%Silt	%Clay
USDA:	66.4	12.8	20.8
ISSS:	72.8	6.4	20.8

Using the Textural Triangle to Determine the Textural Class Name

Soil Scientists have created classes which break the distribution of particle sizes (soil textures) into 12 categories. Textural Triangle 3 is one of the tools soil scientists use to visualize and understand the meaning of soil texture names. This textural triangle is a diagram which shows how each of these 12 textures are classified based on the percent of sand, silt, and clay in each. **Note:** these percentages are based on the USDA definition of sand and silt only.

Follow these steps to determine the textural class name of your soil sample:

1. Place a plastic sheet or tracing paper over Textural Triangle 3.
2. Place the edge of a ruler at the point along the base of the triangle that represents the percent of sand in your sample. Position the ruler on the line that slants in the direction that the numbers are facing for percent sand.
3. Place the edge of a second ruler at the point along the right side of the triangle. Position the ruler on the line which slants in the direction that the numbers are facing for percent silt.
4. Place the point of a pencil or water soluble marker at the point where the two rulers meet. Place the top edge of one of the rulers on the mark, and hold the ruler parallel to the horizontal lines. The number on the left should be the percent of clay in the sample. Note that the sum of the percent of sand, silt, and clay should add up to 100.
5. The descriptive name of the soil sample (textural class) is written in the shaded area where the mark is located. If the mark should fall directly on a line between two descriptions, record both names.

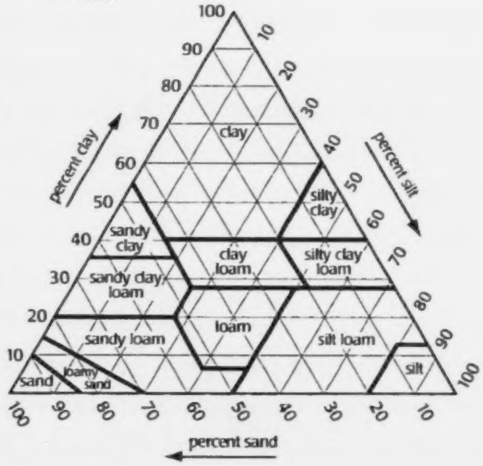


Figure SOIL-L-4: Textural Triangle 3

For the example given above, the textural class of the soil sample would be:

	%Sand	%Silt	%Clay	
USDA:	56.4	12.4	32.2	Sandy Clay Loam

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Practice Exercises

Soil Texture Practice Work Sheet

Use the following numbers to determine the soil texture name using the textural triangle. When a number is missing, fill in the blanks. **Note:** the sum of percents and, silt and clay should always add up to 100 percent:

	% Sand	%Silt	%Clay	Texture Name
a.	75	10	15	sandy loam
b.	10	83	7	___
c.	42	___	37	___
d.	___	52	21	___
e.	___	35	50	___
f.	30	___	55	___
g.	37	___	21	___
h.	5	70	___	___
i.	55	___	40	___
j.	___	45	10	___

Answers: b. silt loam; c. 21, clay loam; d. 27, silt loam; e. 15, clay; f. 15, clay; g. 42, loam; h. 25, silt loam; i. 5, sandy clay; j. 45, loam.

Stoke's Law: To Calculate the Settling Time of Soil Particles

In the Soil Particle Size Distribution Protocol, the readings of the hydrometer had to be taken at a very specific time to allow either the sand or silt to settle in the cylinder. In order to determine this time for each size particle, we use an equation derived from Stoke's Law. Stoke's Law describes how fast (the velocity at which) a particle will settle as a function of its diameter and the properties of the liquid in which it is settling. Once this velocity is known, you can calculate the time required for a particle of a certain diameter to settle a given depth in water.

Stoke's Law can be written in the form of the following equation:

$$V = kd^2$$

where:

V = settling velocity (in cm/second)

d = particle diameter in cm (such as 0.2 cm - 0.005 cm for sand, 0.005 cm- 0.0002 cm for silt, and <0.0002 cm for clay)

k = a constant which depends on the liquid in which the particle is settling, particle density, the force of gravity, and the temperature ($8.9 \times 10^3 \text{ cm}^{-1} \text{ sec}^{-1}$ for soil in water at 20°C).

Example

Suppose you wanted to calculate the amount of time it would take a particle of fine sand (0.1 mm) to settle. The distance between the 500 mL mark on you graduated cylinder and the base of the cylinder is about 27 cm.

1. First, convert the diameter of the particle from mm to cm.

   0.1 mm x 1 cm/10 mm = 0.01 cm

2. Using the equation above, plug in values for the diameter of the particle, square it, and multiply by the constant.

   $$V = 8900 \times (0.01)^2$$

   0.89 cm/second

3. Next, divide the distance between the 500 mL mark and the base on your cylinder by the velocity calculated in step 2.

$$27 \text{ cm}/0.89 \text{ cm second}^{-1} = 30.33 \text{ seconds}$$

Thus, it would take about 30 seconds for fine sand with a diameter of 0.1 mm to settle to the base of the 500 mL cylinder.

Further Investigations

1. Feel the texture of a moist soil sample. Using Textural Triangles 1 and 2 in the *Soil Characterization Field Protocol*, determine the texture. Sand will feel gritty, while silt will feel like powder or flour. Clay will feel sticky and hard to squeeze, and will probably stick to your hand. Look at Textural Triangle 3; find the name of the textural class to which this soil corresponds. Try to estimate how much sand, silt, or clay is in the sample.
2. Practice determining the percent sand, silt, and clay in student samples using the hand "texturing" method along with Textural Triangle 3. Estimates can then be verified with the procedure outlined in the Particle Size Distribution Protocol which will tell them more quantitatively how much of each size particle is in their sample.
3. Once students feel more confident in correctly estimating texture, design a game or competition to see which students can come the closest in their estimation to the actual values determined by the settling method.
4. Develop a set of standard soil texture samples which can be used for students to practice determining soil texture. These standards should include one example of each of the twelve textural classes, with a percent sand, silt, and clay listed that was determined by the settling method.
5. Use the Stoke's Law procedure to calculate the velocity and settling time for a particle with a diameter (in cm) in which students are interested. Be sure to use particle size in cm.

Student Assessment

Verify that students understand the relationship between particle size distribution by testing how well they can determine the textural class of unknown samples by feel. Use practice exercises, such as the ones given above to determine how well they can use the textural triangle.

Acknowledgment:

Adapted from L.J. Johnson. 1979. *Introductory Soil Science: A Study Guide and Laboratory Manual*. MacMillan Pub. Co., Inc., N.Y.

The Data Game

Purpose

To learn how to estimate data results in order to minimize errors in reading or recording data

Overview

Students will participate in a game in which they collect data using various instruments and calculations and then try to fool other data collection teams by exaggerating some of the data numbers. They do this activity first with data about objects in the classroom, then with soil moisture measurements, and then with other GLOBE data.

Time

One class period

Level

All

Key Concepts

Measuring and recording data accurately
Estimates give a "feel" for data quality.
Estimates provide a way to pick out unusual data for further research.

Skills

Measuring and *recording* data
Estimating data values
Evaluating data values based on "reasonableness"

Materials and Tools

For younger students:
Rulers
Measuring tapes
Measuring cups and spoons
For older students:
Instruments for measuring:
a) distance
b) volume
c) circumference
d) weight

Prerequisites

None

Background

Scientists rely on the accuracy of the data submitted by schools. However, even the most careful observer can make a mistake in data collection and recording. It is essential to make sure your data are as accurate as possible. One way to avoid mistakes is to have students critically evaluate any number they write down. Does this number sound reasonable? Is it even possible to have this number? As students become more familiar with the measurements they are taking, they will get a feel for what to expect.

There are two elements necessary for students to judge the reasonableness of data values. First, students have to understand the units of measure: about how far is a meter? How much water is a liter? How much does a liter of water weigh? Second, students need to have a sense of the expected range of data values for the protocol: what are the lowest and highest values one might expect for soil water content? For air temperature?

In this activity, your students will deal with both elements in the form of a game. They will work in groups to collect and record data. Then they change some of the values and have the other students guess which ones are wrong, based on a sense of "reasonableness" of the values.

Using this "reasonableness" criteria is a fundamentally important skill, as it requires students not only to know what values one might expect, but also to take personal responsibility for the accuracy of their data.

It should be stressed that your students may collect accurate data that is unexpected. Estimating what to expect will also help students recognize when their data are unusual and should prompt more investigation.

What To Do and How To Do It

Stage 1 – Estimating data about classroom objects

1. Divide your class into teams of four students. Provide each team with measuring instruments and have the teams collect classroom data. Each team should collect and record 5 to 10 classroom data values.

   Beginning students might:

   count the number of books, tiles, fingers, etc. in the classroom

   measure the length of ten books, the room, around a desk, etc.

   measure the amount of water in a glass, the sink, etc.

   Intermediate students might:

   measure and add distances (the height of a desk and all the desks in the room)

   calculate the height of all text books piled together.

   Advanced students might:

   calculate square meters, cubic centimeters, volume, and weights.
2. Now have each team "disguise" part of their data by exaggerating the numbers. For instance, a cube with a volume of 10 centimeters should be changed to 20 or even 200 centimeters. The less the exaggeration, the greater the challenge for the other students. (You may want to begin with the rule that the exaggerated value is at least double the measured value.)
3. Each team takes turns reporting their data. The other teams must guess whether or not the report is accurate. Each team that is correct gets one point.
4. After all teams have taken turns reporting their data, the team with the most points wins.
5. At the end of the activity, discuss the process of estimating, and the concept of reasonableness. You might want to repeat this activity to see if the students improve.

Stage 2 – Estimating soil water content data

Your students will apply the same concept to soil moisture (you can play the data game with any type of data). You can use soil moisture data that your students have already collected as part of the protocol, or with soil moisture data from the samples students brought from home as part of the activity *How Much Water Does It Hold?*

As described in Stage 1 above, have your students change some of the data values for soil water content, and then have other students guess which values are accurate and which are exaggerated. Score as described above.

Stage 3 – Using data from the GLOBE Student Data Server

1. Have the students access the GLOBE Student Data Server to browse through soil water content data that have been gathered by other GLOBE sites. They should find:

   the range of data for each depth

   the range of data for schools nearby

   the range of data for schools in arid regions or forests or grasslands

   the most common values.
2. Discuss the ranges and common values, and have your students reflect on how this information would help them to do better in the data game.
3. Have your students play the data game again, using global data from the GLOBE Student Data Server.
4. Discuss with your students how this process – reviewing sample data first in order to get a sense of what to expect – is an essential step in estimating values and judging "reasonableness."
5. You can repeat this activity with any of the GLOBE data sets
6. It is also important to point out that abnormal data, often called "outliers," are not necessarily wrong, but certainly need to be looked at closely. Outliers, in fact, are

often the most interesting or important data to investigate further.

7. If any of the values in the GLOBE Student Data Server do not seem correct, then have your students send a GLOBEMail to the school which submitted the data, and ask them if there are reasons for the abnormal value or if they might need to take more care in their next measurement.

Adaptations for Intermediate and Advanced Students

With older students, you can have them graph the data (especially in Stage 3), and then do an analysis of the range, the outliers, the average values, the most common values, and so on. They might also discuss why there are variations from one site to another in the global data set. This in turn relies on a deeper understanding of the science domain, such as soil.

Further Investigations

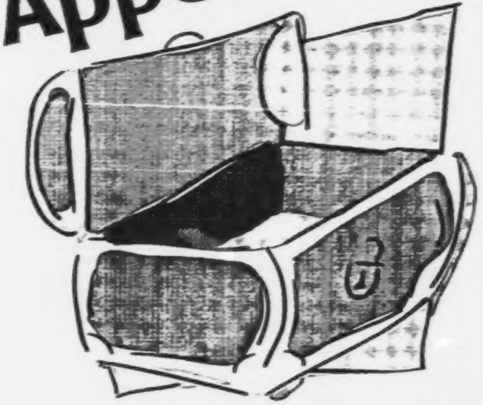
Whenever your students have problems knowing what are typical values for a protocol, you can have them play the data game. Be sure they review the protocol and sample data sets first so that they'll have a basis for assessing reasonableness.

On a regular basis, review the soil water content and other data submitted by other schools to look for errors or outliers, and communicate with the schools by GLOBEMail to discuss any abnormal values.

Student Assessment

Periodically, when your students do the GLOBE protocols, have one of your students announce the values to the class, including an erroneous value, and see if any other students notice the error. You could reward the error-finding with a GLOBE star or other reward appropriate to the age level. Make sure that the error is corrected before your students submit the data to GLOBE!

Appendix



Soil Characterization Data Work Sheet

Bulk Density Data Work Sheet-Pit and Near Surface Techniques

Bulk Density Data Work Sheet-Auger Technique

Particle Size Distribution Data Work Sheet

Soil pH Data Work Sheet

Soil Fertility Data Work Sheet

Soil Moisture Study Site Work Sheet

Soil Moisture Data Work Sheet-Star Pattern

Soil Moisture Data Work Sheet-Transect Pattern

Daily Gypsum Block Data Work Sheet

Annual Gypsum Block Calibration Data Work Sheet

Soil Infiltration Data Work Sheet

Soil Temperature Data Work Sheet

Soil Characterization Information Sheet

Textural Triangle 3

Glossary

GLOBE Web Data Entry Sheets

Soil Investigation

Soil Characterization Data Work Sheet

Site Name: ________________________ *Form Number:* ____________ *Slope:* ______° *MUC:* _______

Method (choose one) Pit or Near Surface ________ *Auger* _______ *Existing Exposed Soil Profile* _____

Other Site Characteristics: ____

HORIZON (letter or number)	TOP DEPTH (cm)	BOTTOM DEPTH (cm)	MOISTURE (wet, moist, dry)	STRUCTURE (type)	MAIN COLOR (code from color book)	SECOND COLOR (code from color book)	CONSISTENCE (loose, friable, firm, extremely firm)	TEXTURE (name)	ROCKS (none, few, many)	ROOTS (none, few, many)	CARBONATES (none, slight, strong)

NOTES:

Soil Investigation

Bulk Density Data Work Sheet - Pit and Near Surface Techniques

Date of Sample Collection: ________ Site: ____________________

Horizon Number: ______________ Horizon Depth: Top ________ cm

Bottom ________ cm

Sample Number 1

A. Container volume: __________ mL

B. Container weight: __________ g

C. Wet weight of sample: __________ g

D. Dry weight of sample: __________ g

E. Dry soil weight (D-B): __________ g

F. Weight of rocks: __________ g

G. Volume of water without rocks: __________ mL

H. Volume of water and rocks: __________ mL

I. Volume of rocks (H-G): __________ mL

J. Bulk density [(E-F)/(A-I)]: __________ g/mL (cm^3)

Sample Number 2

A. Container volume: __________ mL

B. Container weight: __________ g

C. Wet weight of sample: __________ g

D. Dry weight of sample: __________ g

E. Dry soil weight (D-B): __________ g

F. Weight of rocks: __________ g

G. Volume of water without rocks: __________ mL

H. Volume of water and rocks: __________ mL

I. Volume of rocks (H-G): __________ mL

J. Bulk density [(E-F)/(A-I)]: __________ g/mL (cm^3)

Sample Number 3

A. Container volume: __________ mL

B. Container weight: __________ g

C. Wet weight of sample: __________ g

D. Dry weight of sample: __________ g

E. Dry soil weight (D-B): __________ g

F. Weight of rocks: __________ g

G. Volume of water without rocks: __________ mL

H. Volume of water and rocks: __________ mL

I. Volume of rocks (H-G): __________ mL

J. Bulk density [(E-F)/(A-I)]: __________ g/mL (cm^3)

Soil Investigation

Bulk Density Data Work Sheet - Auger Technique

Date of Sample Collection: __________ Site: ____________________
Horizon Number: ____________________ Horizon Depth: Top __________ cm
Bottom __________ cm

Sample Number 1

A. Sample Depth: Top __________ cm
B. Sample Depth: Bottom __________ cm
C. Hole diameter: __________ cm
D. Hole volume $\pi \times (C/2)^2 \times (B-A)$: ________ cm^3
E. Container weight: __________ g
F. Wet weight of sample: __________ g

G. Dry weight of sample: __________ g
H. Dry soil weight (G-E): __________ g
I. Weight of rocks: __________ g
J. Volume of water without rocks: ________ mL
K. Volume of water and rocks: ________ mL
L. Volume of rocks (K-J): __________ mL (cm^3)

M. Bulk density [(H-I)/(D-L)]: __________ g/cm^3

Sample Number 2

A. Sample Depth: Top __________ cm
B. Sample Depth: Bottom __________ cm
C. Hole diameter: __________ cm
D. Hole volume $\pi \times (C/2)^2 \times (B-A)$: ________ cm^3
E. Container weight: __________ g
F. Wet weight of sample: __________ g

G. Dry weight of sample: __________ g
H. Dry soil weight (G-E): __________ g
I. Weight of rocks: __________ g
J. Volume of water without rocks: ________ mL
K. Volume of water and rocks: ________ mL
L. Volume of rocks (K-J): __________ mL (cm^3)

M. Bulk density [(H-I)/(D-L)]: __________ g/cm^3

Sample Number 3

A. Sample Depth: Top __________ cm
B. Sample Depth: Bottom __________ cm
C. Hole diameter: __________ cm
D. Hole volume $\pi \times (C/2)^2 \times (B-A)$: ________ cm^3
E. Container weight: __________ g
F. Wet weight of sample: __________ g

G. Dry weight of sample: __________ g
H. Dry soil weight (G-E): __________ g
I. Weight of rocks: __________ g
J. Volume of water without rocks: ________ mL
K. Volume of water and rocks: ________ mL
L. Volume of rocks (K-J): __________ mL (cm^3)

M. Bulk density [(H-I)/(D-L)]: __________ g/cm^3

Soil Investigation

Particle Size Distribution Data Work Sheet

Date of Sample Collection: __________ Site: ____________________________

Horizon Number: __________________ Horizon Depth: Top ______ cm

Bottom ______ cm

Distance from 500 mL mark to base of graduated cylinder: __________ cm

Hydrometer Calibration Temperature ________ °C

Sample Number 1

A. 2 minute hydrometer reading: _______

B. 2 minute temperature: __________ °C

C. 12 minute hydrometer reading: _______

D. 12 minute temperature: __________ °C

E. 24 hour hydrometer reading: __________

F. 24 hour temperature: __________ °C

Sample Number 2

A. 2 minute hydrometer reading: _______

B. 2 minute temperature: __________ °C

C. 12 minute hydrometer reading: _______

D. 12 minute temperature: __________ °C

E. 24 hour hydrometer reading: __________

F. 24 hour temperature: __________ °C

Sample Number 3

A. 2 minute hydrometer reading: _______

B. 2 minute temperature: __________ °C

C. 12 minute hydrometer reading: _______

D. 12 minute temperature: __________ °C

E. 24 hour hydrometer reading: __________

F. 24 hour temperature: __________ °C

Soil Investigation

Soil pH Data Work Sheet

Date of Sample Collection: __________ Site: ______________________________

pH Measurement method (check one): _____paper ______pen _____meter

---

Horizon Number:________

Horizon Depth: Top _____ cm

Bottom _____ cm

Sample Number 1	***Sample Number 2***	***Sample Number 3***
A. pH of water before adding soil: _____	A. pH of water before adding soil: _____	A. pH of water before adding soil: _____
B. pH of soil and water mixture: _____	B. pH of soil and water mixture: _____	B. pH of soil and water mixture: _____

Horizon Number:________

Horizon Depth: Top _____ cm

Bottom _____ cm

Sample Number 1	***Sample Number 2***	***Sample Number 3***
A. pH of water before adding soil: _____	A. pH of water before adding soil: _____	A. pH of water before adding soil: _____
B. pH of soil and water mixture: _____	B. pH of soil and water mixture: _____	B. pH of soil and water mixture: _____

Horizon Number:________

Horizon Depth: Top _____ cm

Bottom _____ cm

Sample Number 1	***Sample Number 2***	***Sample Number 3***
A. pH of water before adding soil: _____	A. pH of water before adding soil: _____	A. pH of water before adding soil: _____
B. pH of soil and water mixture: _____	B. pH of soil and water mixture: _____	B. pH of soil and water mixture: _____

Soil Investigation

Soil Fertility Data Work Sheet

Date of Sample Collection: __________ Site: __________________________

Horizon Number: ________ Horizon Depth: Top ________cm

Bottom ________cm

Sample Number 1

Nitrate (N): High__ Med__ Low__ None__

Phosphorus (P): High__ Med__ Low__ None__

Potassium (K): High__ Med__ Low__ None__

Sample Number 2

Nitrate (N): High__ Med__ Low__ None__

Phosphorus (P): High__ Med__ Low__ None__

Potassium (K): High__ Med__ Low__ None__

Sample Number 3

Nitrate (N): High__ Med__ Low__ None__

Phosphorus (P): High__ Med__ Low__ None__

Potassium (K): High__ Med__ Low__ None__

Horizon Number: ________ Horizon Depth: Top ________cm

Bottom ________cm

Sample Number 1

Nitrate (N): High__ Med__ Low__ None__

Phosphorus (P): High__ Med__ Low__ None__

Potassium (K): High__ Med__ Low__ None__

Sample Number 2

Nitrate (N): High__ Med__ Low__ None__

Phosphorus (P): High__ Med__ Low__ None__

Potassium (K): High__ Med__ Low__ None__

Sample Number 3

Nitrate (N): High__ Med__ Low__ None__

Phosphorus (P): High__ Med__ Low__ None__

Potassium (K): High__ Med__ Low__ None__

Horizon Number: ________ Horizon Depth: Top ________cm

Bottom ________cm

Sample Number 1

Nitrate (N): High__ Med__ Low__ None__

Phosphorus (P): High__ Med__ Low__ None__

Potassium (K): High__ Med__ Low__ None__

Sample Number 2

Nitrate (N): High__ Med__ Low__ None__

Phosphorus (P): High__ Med__ Low__ None__

Potassium (K): High__ Med__ Low__ None__

Sample Number 3

Nitrate (N): High__ Med__ Low__ None__

Phosphorus (P): High__ Med__ Low__ None__

Potassium (K): High__ Med__ Low__ None__

Soil Investigation

Soil Moisture Study Site Work Sheet

Create a unique name for your site and give concise directions to it.

Site name: ____

Directions: ____

____

Coordinates: LATITUDE: __________ LONGITUDE: __________ ELEV: _______ m

Source of Lat/Lon (check one): GPS _____ Other _____

Site Metadata

Distance to nearest rain gauge or instrument shelter: ____ m; Direction _______
Distance to nearest Soil Characterization Sample Site: ____ m; Direction _______

State of Soil Moistur Study Site:
Natural ___, Plowed ___, Graded ___, Backfill ___, Compacted ___, Other ___

Surface Cover:
Bare Soil ___, Short grass (<10 cm) ___, Long grass (10 cm) ___

Canopy Cover:
Open ___, Some Trees within 30 m ___, Canopy Overhead ___
Structures within 30 m: No ___, Yes (describe size) ________________________

Soil Characterization:
(Take these values from the Soil Characterization Data Work Sheet for the nearest Soil Characterization Sample Site.)

	0-5 cm	10 cm	30 cm	60 cm	90 cm
Structure					
Color					
Consistence					
Texture					
Rocks:					
Roots:					
Bulk Density					

Soil Particle Size Distribution:

% Sand					
% Silt					
% Clay					

Did you choose USDA ________ or ISSS ________ definitions of sand and silt?

Soil Moisture Study Site Work Sheet (continued)

Land Cover Classification: (follow Land Cover protocol)

Most detailed MUC Code ____________________
Enter MUC Name ____________________

Collector's comments:

____
____
____
____
____
____
____
____
____

Site Sketch:

(Scale 1 square = _______)

Soil Investigation

Soil Moisture Data Work Sheet - Star Pattern

Site Name: ______________________________

Name of Collector/Analyst/Recorder: ______________________________

Sample collection date: _______

time: _______ (hours and minutes) check one: UT___ Local ___

Current Conditions: Is soil saturated? Yes _____ No _____

Drying Method: 95-105° C oven ____; 75-95° C oven ____; microwave ____

Average Drying Time: _________(hours or minutes)

Bearing from Star Center (optional): ________ Distance from Star Center: ________

Observations:

Near-surface Samples:

Sample Number	Sample Depth	Container Number	A. Wet Weight (g)	B. Dry Weight (g)	C. Water Weight (A-B)	D. Container Weight (g)	E. Dry Soil Weight (B-D)	F. Soil Water Content (C/E)x100
1	0-5 cm							
	10 cm							
2	0-5 cm							
	10 cm							
3	0-5 cm							
	10 cm							

Depth Samples:

Sample Depth	Container Number	A. Wet Weight (g)	B. Dry Weight (g)	C. Water Weight (A-B)	D. Container Weight (g)	E. Dry Soil Weight (B-D)	F. Soil Water Content (C/E)x100
0-5 cm							
10 cm							
30 cm							
60 cm							
90 cm							

Soil Investigation

Soil Moisture Data Work Sheet - Transect Pattern

Site Name: ______________________________

Name of Collector/Analyst/Recorder: ______________________

Sample collection date: _______

time: _______ (hours and minutes) check one: UT___ Local ___

Current Conditions: Is soil saturated? Yes _____ No _____

Drying Method: 95-105 °C oven ____; 75-95 °C oven ____; microwave ____

Average Drying Time: _________(hours or minutes)

Daily Metadata: (optional)

Length of Line: ________ m Compass Bearing: ______ Station Spacing: _____ m

Directions:

Transects should be 50 m long, located in an open field. Measurements are made 12 times/yr. during a regular interval of your choice. Enter the data for your samples collected between 0-5 cm (10 single samples plus 1 triple sample):

Observations:

Sample Number	Offset from end of Transect (m)	Container Number	A. Wet Weight (g)	B. Dry Weight (g)	C. Water Weight (A-B)	D. Container Weight (g)	E. Dry Soil Weight (B-D)	F. Soil Water Content (C/E)x100
1								
2								
3								
4								
3								
5								
6								
7								
8								
9								
10								
11								
12								
13								

Soil Investigation

Daily Gypsum Block Data Work Sheet

Site Name: ______________________________

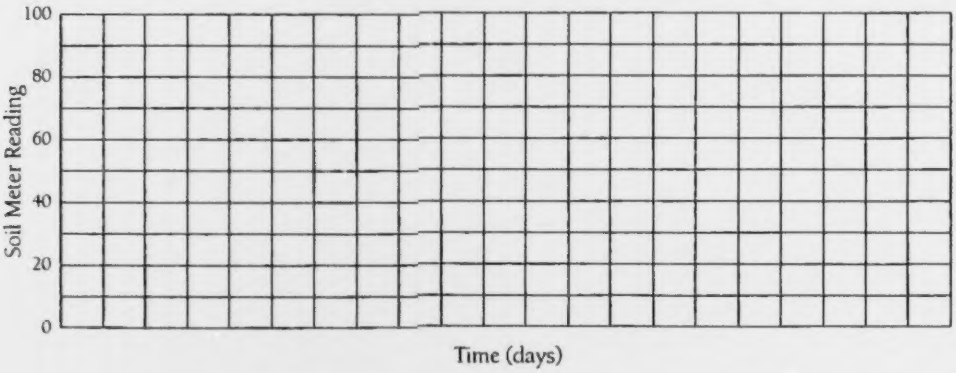
School Name and Address: ______________________________

GLOBE Teacher name: ______________________________

Date you started to use this SWC calibration curve: __________

Observations:

Measurement					Soil Moisture Meter Readings				SWC from Calibration Curve			
#	Date	Time (UT)	Is the soil saturated? Yes or No	Observers' Names	10 cm	30 cm	60 cm	90 cm	10 cm	30 cm	60 cm	90 cm
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												



Soil Investigation

Annual Gypsum Block Calibration Data Work Sheet

Site Name: ______________________________

School Name and Address: ______________________________

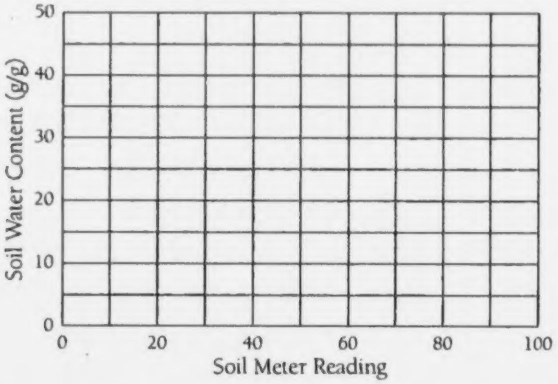
GLOBE Teacher name: ______________________________

Drying Method (check one): 95-105 °C oven ___; 75-95 °C oven ___; microwave____

Average Drying Time: ________ (hours or minutes)

Observations:

Measurement				Data for 30 cm depth only						
#	Date	Time (UT)	Observers' Name	A. Wet Weight (g)	B. Dry Weight (g)	C. Water Weight (A-B)	D. Can Weight (g)	E. Dry Soil Weight (B-D)	F. Soil Water Content (C/E)x100	G. Meter Reading
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										



Soil Investigation

Soil Infiltration Data Work Sheet

Site Name: ____

Name of Collector/Analyst/Recorder: ____________________________

Sample collection date: _______

time: _______ (hours and minutes) check one: UT___ Local ___

Distance to Soil Moisture study site marker _____ m

Sample Set number: _______ Width of your reference band: ______ mm

Diameter: Inner Ring: ______ cm Outer Ring: _______ cm

Heights of reference band above ground level: Upper : _____ mm Lower : ______ mm

Saturated Soil Water Content below infiltrometer after the experiment:

A. Wet Weight: _____ g B. Dry Weight: _____ g C. Water Weight (A–B): _____ g

D. Container Weight: _____ g E. Dry Soil Weight (B–D): _____ g F. Soil Water Content (C/E) x 100 _____

Daily Metadata/Comments: (optional)

Directions:

Take 3 sets of infiltration rate measurements within a 5 m diameter area. Use a different data work sheet for each set. Each set consists of multiple timings of the same water level drop or change until the flow rate becomes constant or 45 minutes is up. Record your data below for one set of infiltration measurements you take.

The form below is setup to help you calculate the flow rate.

For data analysis, plot the Flow Rate (F) vs. Midpoint time (D).

Observations:

	A. Start		B. End		C. Interval (min) (B-A)	D. Midpoint (min) (A+C/2)	E. Water Level Change (mm)	F. Flow Rate (mm/min) (E/C)
	(min)	(sec)	(min)	(sec)				
1	__	__	__	__	____	____	____	____
2	__	__	__	__	____	____	____	____
3	__	__	__	__	____	____	____	____
4	__	__	__	__	____	____	____	____
5	__	__	__	__	____	____	____	____
6	__	__	__	__	____	____	____	____
7	__	__	__	__	____	____	____	____
8	__	__	__	__	____	____	____	____
9	__	__	__	__	____	____	____	____

Soil Investigation

Soil Temperature Data Work Sheet

Site Name: ____________________

Name of Collector/Analyst/Recorder: ____________________

Sample collection date: _______

time: _______ (hours and minutes) check one: UT___ Local ___

Soil Thermometer: Dial ______ Digital ______ Other _____

Current Conditions: Rain within last 24 hours? Yes _____ No _____

Daily Metadata/Comments: (optional)

Directions:

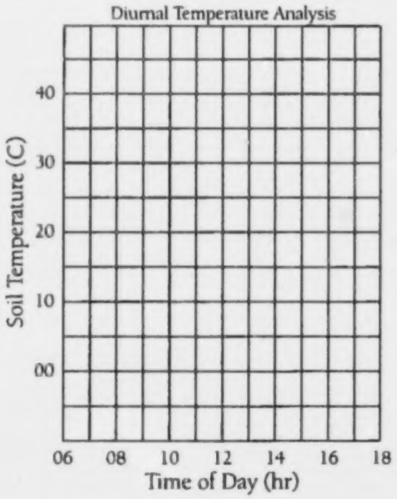
Take 3 sets of soil temperature measurements adjacent to your soil moisture STAR pattern or Atmosphere Instrument Shelter at 5 and 10 cm depth on a weekly basis. Use sample lines 1-3 below (3 samples x 2 depths = 6 measurements). Complete these measurements within 20 minutes of one another and within 1 hour of local solar noon.

OR

Measure the diurnal variation of soil temperature seasonally or at least 3 times/yr. by measuring soil temperature at 5 and 10 cm every 2 to 3 hours during the daytime. Use as many sample lines below as you have measurement times (try to have at least 5). This must be done on two consecutive days. Report each day separately. Additional space is available for classes who want to report diurnal data more frequently or for more hours. Use the graph below to plot soil temperature vs. time-of-day.

Observations:

Sample	**Time**		**Temperature**	
No.	(hr)	(min)	5cm (C)	10 cm (C)
1	____	____	____	____
2	____	____	____	____
3	____	____	____	____
4	____	____	____	____
5	____	____	____	____
6	____	____	____	____
7	____	____	____	____
8	____	____	____	____

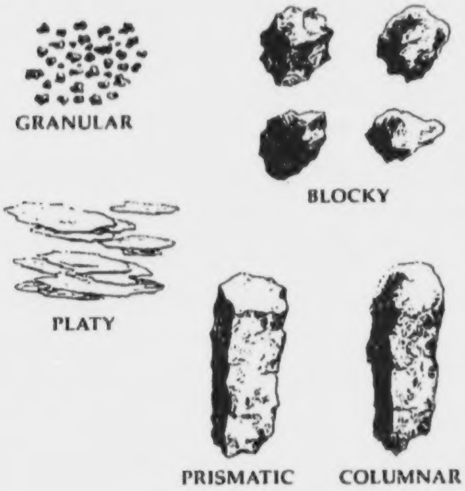


Soil Investigation

Soil Characterization Information Sheet

A: Soil Structure

Take a sample of undisturbed soil in your hand (either from the pit or from the shovel or auger). Look closely at the soil in your hand and examine its structure. Soil structure is the shape that the soil takes based on its physical and chemical properties. Each individual unit of soil structure is called a ped. Some possible choices of soil structure are:



Choices of Soil Structure

Sometimes, your soil may be structureless, which means that within a horizon, soil peds may not have a shape. In this case, the soil structure may be single grained or massive. Single grained is like sand at a beach or in a playground where there are individual sand particles that do not stick together. Massive is when the soil sticks together in a large mass that does not break in any pattern.

It is common to see more than one type of structure in a soil sample. Record on your data sheets only the structure type that is most common in your sample. Discuss and agree upon the main structure type you see. If the sample is structureless, record whether it is single-grained or massive.

B: Soil Color

Take a ped from each horizon and note on the data sheet whether it is moist, dry, or wet. If it is dry, moisten it slightly with water from your water bottle. Break the ped and compare the color of the inside surface with the soil color chart. Stand with the sun over your shoulder so that sunlight shines on the color chart and the soil sample you are examining. Record on the data sheet the code (letter and number) of the color on the chart that most closely matches the soil's color. Sometimes, a soil sample may have more than one color. Record a maximum of two colors if necessary, and indicate (1) the Main Color, and (2) the Second Color. Again, reach an agreement on these colors.

C: Soil Consistence

Take a ped from the soil horizon. Record on the data sheet whether the ped is moist, wet or dry. If the soil is very dry, moisten the face of the profile using a water bottle with a squirt top, and then remove a ped for determining consistence. Holding it between your thumb and forefinger, gently squeeze it until it pops or falls apart. Record one of the following categories of soil ped consistence on the data work sheet.

Loose: You have trouble picking out a single ped and the structure falls apart before you handle it.

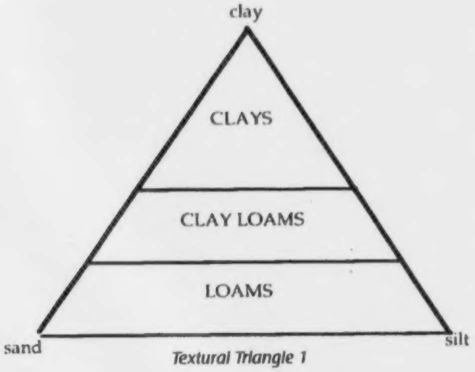
Friable: The ped breaks with a small amount of pressure.

Firm: The ped breaks when you apply a good amount of pressure and dents your fingers before it breaks.

Extremely Firm: The ped can not be crushed with your fingers (you need a hammer!).

D: Soil Texture

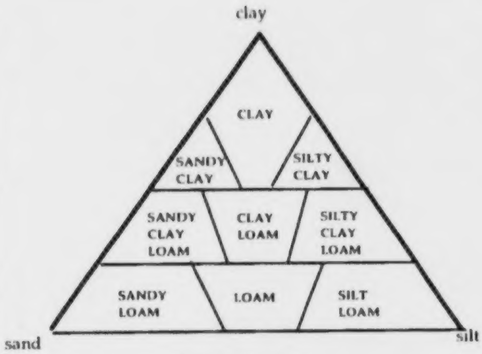
The texture of a soil describes the way the soil feels when you rub it between your fingers. The texture differs depending on the size of the particles in the soil. Sand, silt, and clay are names that describe the size of individual particles in the soil. Sand is the largest size and feels gritty to touch. Silt is medium size and feels *floury* or silky. Clay is the smallest size particle and feels sticky or hard to squeeze. It is more common to find a combination of these different particle sizes in a soil sample. Use the following procedure and the 2 textural triangles below to determine the texture name of each soil horizon in the profile.



Textural Triangle 1

1. Take a sample of soil about the size of a golf ball and add enough water to moisten it. Work it between your fingers until it is the same moisture throughout. Then, squeeze it between your thumb and forefinger in a snapping motion to try to form a ribbon of soil.
2. Refer to Textural Triangle 1 and feel for clay. Clay feels extremely sticky (sticks to your hands and is hard to work), is stiff and requires a lot of thumb and finger pressure to form a ribbon. If this is what your sample feels like, it should be classified as a clay, as shown on Textural Triangle 1.
3. If the soil feels slightly sticky and a little softer to squeeze, it is classified as a clay loam on Textural Triangle 1 and consists of clay, silt and sand particles.
4. If the soil is soft, smooth, and easy to squeeze, it is classified as a loam on Textural Triangle 1.

Next, refine your texture name using Textural Triangle 2:



Textural Triangle 2

1. Feel the same soil sample, but focus on the feeling of sand. If the soil feels very smooth, with no sandy grittiness, add either the word silt or silty to your classification (from Textural Triangle 1), such as silty clay, as shown on Textural Triangle 2. This means that your soil sample has more silt-size particles than sand-size particles.
2. If the soil feels very gritty, add the term sandy to your original soil classification (from Textural Triangle 1), such as sandy clay, as shown on Textural Triangle 2. This means your soil sample has more sand size particles than silt size particles.
3. If you feel some sand, but not a lot, this means it has approximately the same amounts of sand and silt size particles. Your original classification from Textural Triangle 1 (clay, clay loam, or loam) remains the same.

The soil texture can also feel different depending on how wet or dry it is, how much organic matter is in it, and the kind of clay minerals in it. When feeling the soil texture, be sure to add the same amount of water to each soil sample so that you can more accurately compare textures to each other.

Record on the data work sheet the name of the soil texture that the students agree on. If it is close between two different types of texture, list both. Also, note whether the sample was dry, wet, or moist when it was examined.

E. Presence of Roots

Observe and record if there are none, few, or many roots in the horizon

F. Presence of Rocks

Observe and record if there are none, few, or many rocks in the horizon. A rock is defined as being larger than 2 mm in size.

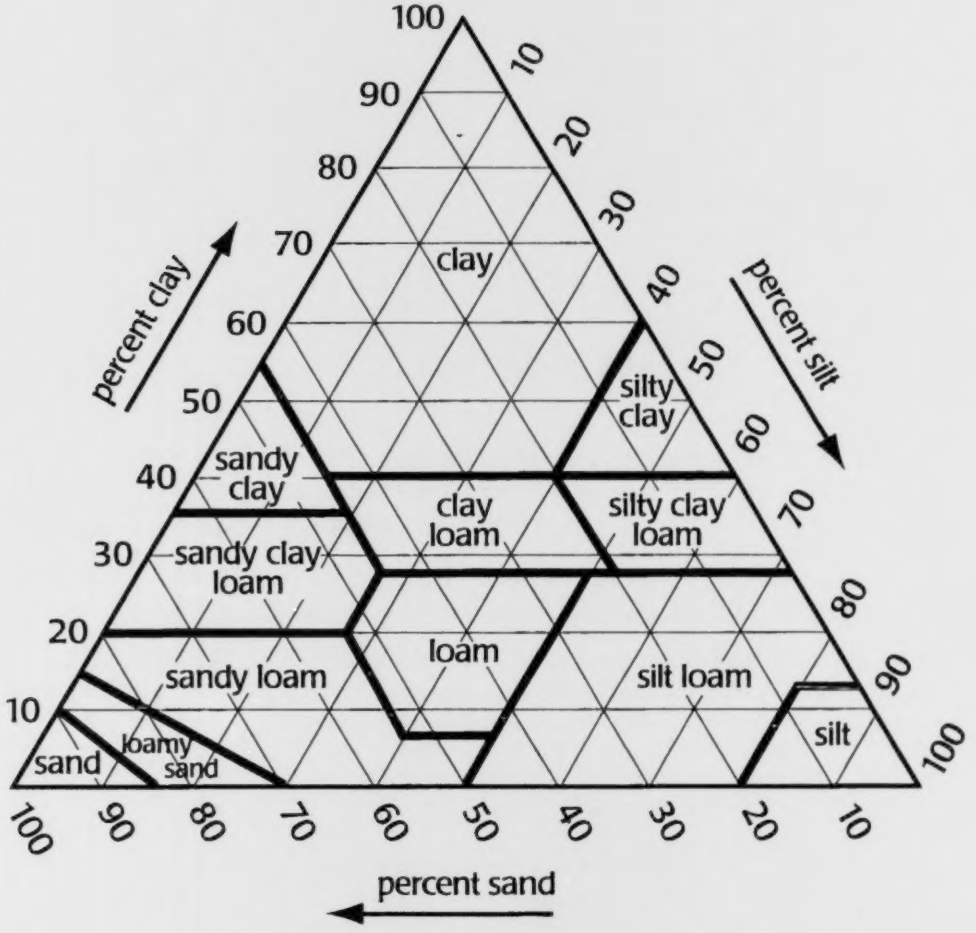
G. Test for Free Carbonates

Perform this test by squirting vinegar on the soil. If carbonates are present, there will be a chemical reaction between the vinegar and the carbonates to produce carbon dioxide. When carbon dioxide is produced, it bubbles or *effervesces*. The more carbonates that are present, the more bubbles (*effervescence*) you will observe.

1. Look carefully at your soil profile for white coatings on the soil and rocks which might indicate that free carbonates are present.
2. Set aside a portion of the pit or sample from the auger hole which you do not touch with your hands and use it for the free carbonates test.
3. After you have finished characterizing the other soil properties, test for free carbonates. Open the acid bottle and starting from the bottom of the profile and moving up, squirt vinegar on the soil particles. Observe carefully for the presence of effervescence.
4. For each horizon record one of the following as the results of the Free Carbonate Test:
    - None: if you observe no reaction, the soil has no free carbonates present.
    - Slight: if you observe a very slight bubbling action; this indicates the presence of some carbonates.
    - Strong: if there is a strong reaction (many, large bubbles) this indicates that many carbonates are present.
5. If you used the auger technique, place the sample back into the hole when you are finished. Do not bring it back to the classroom.

Soil Investigation

Textural Triangle 3


100
90
80
70
60
50
40
30
20
10
percent clay
10
20
30
40
50
60
70
80
90
100
percent silt
100
90
80
70
60
50
40
30
20
10
percent sand
clay
silty clay
sandy clay
clay loam
silty clay loam
sandy clay loam
loam
sandy loam
silt loam
silt
sand
loamy sand

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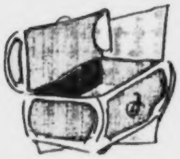
Glossary



alluvial
Transported by water from one place to another.

columnar
A type of soil structure where the soil peds (or chunks) are in the shape of a column with a rounded top. This is found in arid regions.

concretion
A nodule composed of concentrated chemicals in a soil (e.g. iron oxides, manganese oxides, calcium carbonates).

dissolution
Soils, among other compounds, start dissolving into smaller units when placed in contact with water.

dinural cycle
A daily cycle, a basic repetition period of 24 hours. All processes that are dominated by the sun are dinural. Tides, in contrast, repeat cycles twice daily.

effervescence
The bubbling action that occurs as a gas comes out of a liquid for example when the carbon dioxide gas caused by the reaction of carbonate coatings on soil with an acid bubbles through acidic liquid.

eluviation
The removal of materials in one horizon which are then "illuviated" or deposited into a lower horizon.

erosion
The removal and movement of soil materials by water, wind, ice, or gravity as well as by human activities such as agriculture or construction.

evaporation
Water on Earth's surface or in the soil absorbs heat from the sun to the point that it vaporizes or evaporates and becomes part of the atmosphere.

face
The way an exposed section of soil or soil profile appears.

floury
Having the feel of wheat flour – smooth and powdery.

free carbonates
Carbonate materials that form coatings on soil that react with an acid to form carbon dioxide gas.

friable
A type of soil consistence in which the soil ped "pops" when squeezed between the thumb and fore finger with a small amount of pressure.

gravimetric
Relating to measurement by weight or variations in a gravitational field.

horizon
An individual layer within the soil which has its own unique characteristics (such as color, structure, texture, or other properties) that make it different from the other layers in the soil profile.

humus
The part of the soil profile that is composed of decomposed organic matter from dead and decaying plants and animals.

hydrometer
An instrument based on the principles of buoyancy used to measure the specific gravity of a liquid in relation to the specific gravity os pure water at a specified temperature.

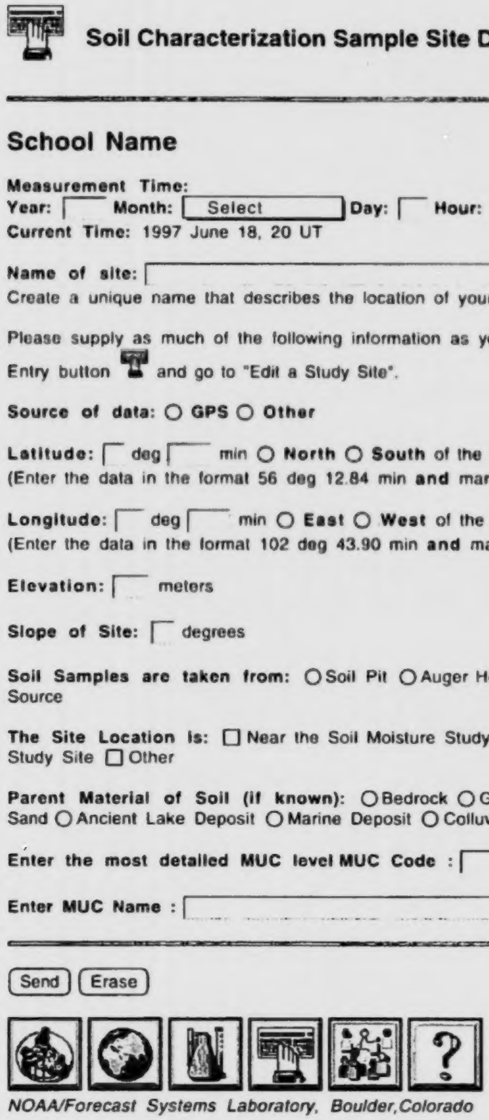
illuviation
The deposit of materials carried by water from one horizon into another within the soil (such as clay or nutrients in solution).

in situ
Latin for the original position.

lithosphere
The outer layer of soul and rock on a planet is called the "lithosphere" after the Greek word "lithos" meaning "stone."

litter	The covering over the soil in a forest made up of leaves, needles, twigs, branches, stems, and fruits from the surrounding trees.
metadata	Data about data. Soil moisture data requires metadata describing the vegetation cover and possible sources of water in order to be interpreted properly.
nomenclature	A particular naming convention agreed to by many individuals or scientists.
organic matter	Any plant or animal material added to the soil.
particle size distribution	The amount (percent) of each of sand, silt, and clay in a soil sample.
ped	An individual unit of natural soil structure or aggregation (such as granular, blocky, columnar, prismatic, or platey).
pedogenesis	The formation of soil profiles depending on the five soil-forming factors (climate, parent material, topography, organisms, and time) to create the Pedosphere.
pedosphere	The thin outer layer of the Earth which is made up of soil. The pedosphere acts as an integrator between the atmosphere, biosphere, lithosphere, and hydrosphere of the Earth.
prismatic	A type of soil structure in which the soil ped is in the shape of a prism.
soil consistence	How easy or hard it is for a soil ped to break apart when it is squeezed.
soil horizons	An identifiable soil unit due to color, structure, or texture.
soil profile	The "face" of a soil when it has been cut vertically that shows the individual horizons and soil properties with depth.
soil structure	The shape of soil units (peds) that occur naturally in a soil horizon. Some possible soil structures are granular, blocky, prismatic, columnar, or platy. Soils can also be structureless if they do not form into peds. In this case, they may be a consolidated mass (massive) or stay as individual particles (single-grained).
soil texture	The way soil "feels" when it is squeezed between the fingers or in the hand. The texture depends on the amount of sand, silt, and clay in the sample (particle size distribution), as well as other factors (how wet it is, how much organic matter is in the sample, the kind of clay, etc.).
subsoil	The common term for the layers beneath the topsoil.
supernatant	Liquid above the settled soil that is cleaner than the soil
topsoil	The common term for the top layer of soil.
transect	In any field (outdoor) study, a transect consists of a line of study, often divided into intervals where observations or samples are collected.
transpiration	Water in plants escapes or transpires into the atmosphere as the leaf stomates open to exchange carbon for oxygen.
uniform	This term is used in its traditional sense that some characteristic displays similar properties, Two related words are homogeneous (distributed evenly) and normal (distributed about a central mean value and described by a statistical equation).

Soil Investigation



Soil Characterization Sample Site Data Entry Sheet

School Name

Measurement Time:
Year: ☐ **Month:** Select **Day:** ☐ **Hour:** ☐ **UT**
Current Time: 1997 June 18, 20 UT

Name of site: ☐
Create a unique name that describes the location of your site.

Please supply as much of the following information as you can now. When you obtain additional information click on the Data Entry button and go to "Edit a Study Site".

Source of data: ○ **GPS** ○ **Other**

Latitude: ☐ deg ☐ min ○ **North** ○ **South** of the Equator
(Enter the data in the format 56 deg 12.84 min **and** mark whether it is North or South.)

Longitude: ☐ deg ☐ min ○ **East** ○ **West** of the Prime Meridian
(Enter the data in the format 102 deg 43.90 min **and** mark whether it is East or West.)

Elevation: ☐ meters

Slope of Site: ☐ degrees

Soil Samples are taken from: ○ Soil Pit ○ Auger Hole ○ 10cm of the Soil Surface ○ Excavation ○ Road Cut ○ Other Source

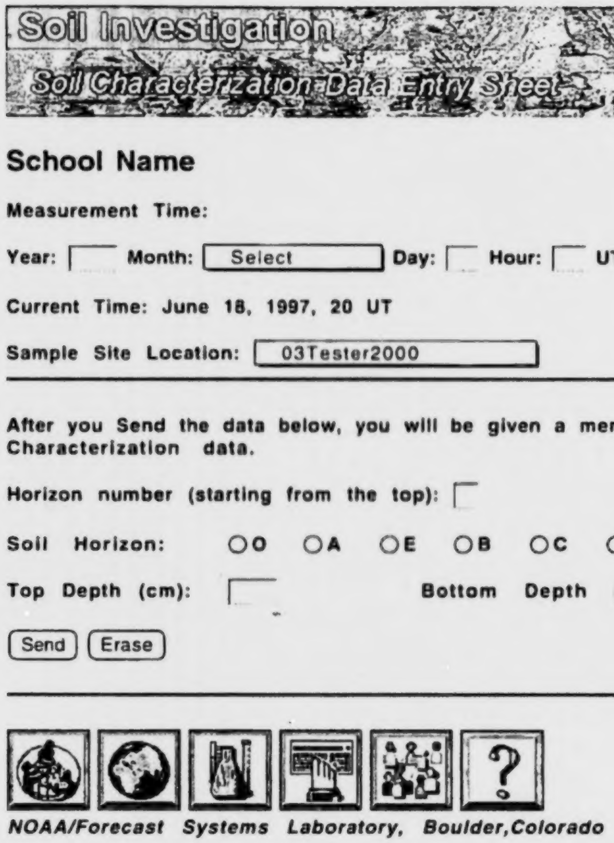
The Site Location is: ☐ Near the Soil Moisture Study Site ☐ Near the Surface Water Study Site ☐ In or Near the Biology Study Site ☐ Other

Parent Material of Soil (if known): ○ Bedrock ○ Glacial Deposit ○ Volcanic Deposit ○ Stream Deposit ○ Wind Blown Sand ○ Ancient Lake Deposit ○ Marine Deposit ○ Colluvium Deposit ○ Other ○ Don't Know

Enter the most detailed MUC level MUC Code : ☐

Enter MUC Name : ☐

NOAA/Forecast Systems Laboratory, Boulder,Colorado



Soil Investigation
Soil Characterization Data Entry Sheet

School Name

Measurement Time:

Year: ☐ **Month:** Select **Day:** ☐ **Hour:** ☐ **UT**

Current Time: June 18, 1997, 20 UT

Sample Site Location: 03Tester2000

After you Send the data below, you will be given a menu for you to enter your remaining Soil Characterization data.

Horizon number (starting from the top): ☐

Soil Horizon: ○ O ○ A ○ E ○ B ○ C ○ R

Top Depth (cm): ☐ **Bottom Depth (cm):** ☐

Send
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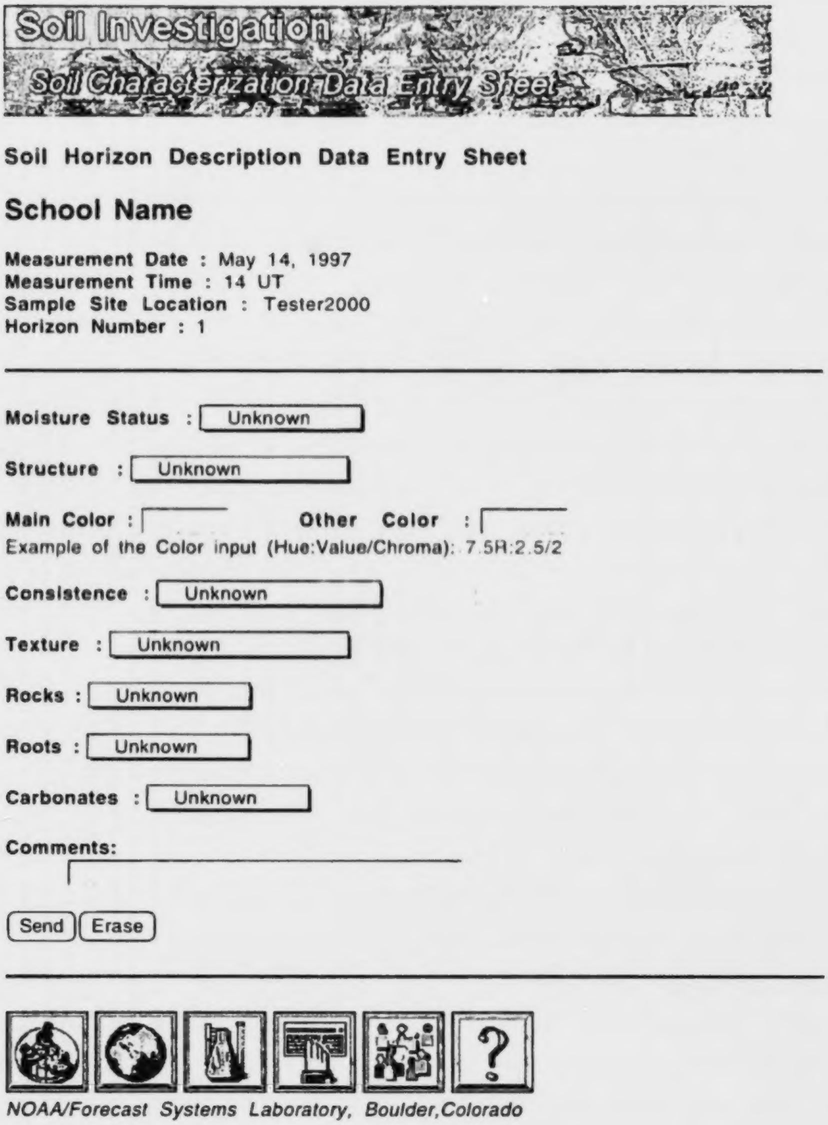

Soil Investigation

Soil Characterization Data Entry Sheet

Soil Horizon Description Data Entry Sheet

School Name

Measurement Date : May 14, 1997
Measurement Time : 14 UT
Sample Site Location : Tester2000
Horizon Number : 1

Moisture Status : Unknown

Structure : Unknown

Main Color : **Other Color :**
Example of the Color input (Hue:Value/Chroma): 7.5R:2.5/2

Consistence : Unknown

Texture : Unknown

Rocks : Unknown

Roots : Unknown

Carbonates : Unknown

Comments:

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Soil Investigation

Soil Characterization Data Entry Sheet

Soil Bulk Density Data Entry Sheet

School Name

Measurement Date : May 14, 1997
Measurement Time : 14 UT
Sample Site Location : Tester2000
Horizon Number : 1

Sample 1

For Pit Method :
- **Volume of Sample:** mL

For Auger Method :
- **Sample Top Depth :** cm
- **Sample Bottom Depth:** cm
- **Hole Diameter:** cm

Weight of moist soil and container: g
Weight of dry soil and container: g
Weight of empty container: g
Weight of rocks contained in dry soil sample: g
Volume of water before addition of rocks: mL
Volume of water after addition of rocks: mL

Bulk Density: g/mL

Sample 2

For Pit Method :
- **Volume of Sample:** mL

For Auger Method :
- **Sample Top Depth:** cm
- **Sample Bottom Depth :** cm
- **Hole Diameter:** cm

Weight of moist soil and container: g
Weight of dry soil and container: g
Weight of empty container: g
Weight of rocks contained in dry soil sample: g
Volume of water before addition of rocks: mL
Volume of water after addition of rocks: mL

Bulk Density: g/mL

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Sample 3

For Pit Method :
Volume of Sample: ☐ mL

For Auger Method :
Sample Top Depth: ☐ cm
Sample Bottom Depth: ☐ cm
Hole Diameter: ☐ cm

Weight of moist soil and container: ☐ g
Weight of dry soil and container: ☐ g
Weight of empty container: ☐ g
Weight of rocks contained in dry soil sample: ☐ g
Volume of water before addition of rocks: ☐ mL
Volume of water after addition of rocks: ☐ mL

Bulk Density: ☐ g/mL

Comments:

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Soil Investigation

Soil Characterization Data Entry Sheet

Soil Particle-Size Distribution 1996 Method Data Entry Sheet

School Name

Measurement Date : May 14, 1997
Measurement Time : 14 UT
Sample Site Location : Tester2000
Horizon Number : 1

Sample 1
Total Soil (mL): **40 Seconds (mL):** **30 Minutes (mL):**

Sample 2

Total Soil (mL): **40 Seconds (mL):** **30 Minutes (mL):**

Sample 3

Total Soil (mL): **40 Seconds (mL):** **30 Minutes (mL):**

Comments:

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Soil Investigation

Soil Characterization Data Entry Sheet

Soil Particle Size Distribution Hydrometer Method Data Entry Sheet

School Name

Measurement Date : May 14, 1997
Measurement Time : 14 UT
Sample Site Location : Tester2000
Horizon Number : 1

Temperature the Hydrometer was calibrated: 15.5 degrees Celsius
Distance between 500 mL line to base of cylinder: cm

Sample 1

Hydrometer Readings:

2 minutes: (USDA standard for silt and clay left in suspension)
12 minutes: (ISSS standard for silt and clay left in suspension)
24 hours: (Clay left in suspension)

Temperature of Water and Soil Mixture:

2 minutes: degrees C
12 minutes: degrees C
24 hours: degrees C

Sample 2

Hydrometer Readings:

2 minutes: (USDA standard for silt and clay left in suspension)
12 minutes: (ISSS standard for silt and clay left in suspension)
24 hours: (Clay left in suspension)

Temperature of Water and Soil Mixture:

2 minutes: degrees C
12 minutes: degrees C
24 hours: degrees C

Sample 3

Hydrometer Readings:

2 minutes: (USDA standard for silt and clay left in suspension)
12 minutes: (ISSS standard for silt and clay left in suspension)
24 hours: (Clay left in suspension)

Temperature of Water and Soil Mixture:

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2 minutes: degrees C
12 minutes: degrees C
24 hours: degrees C

Comments:

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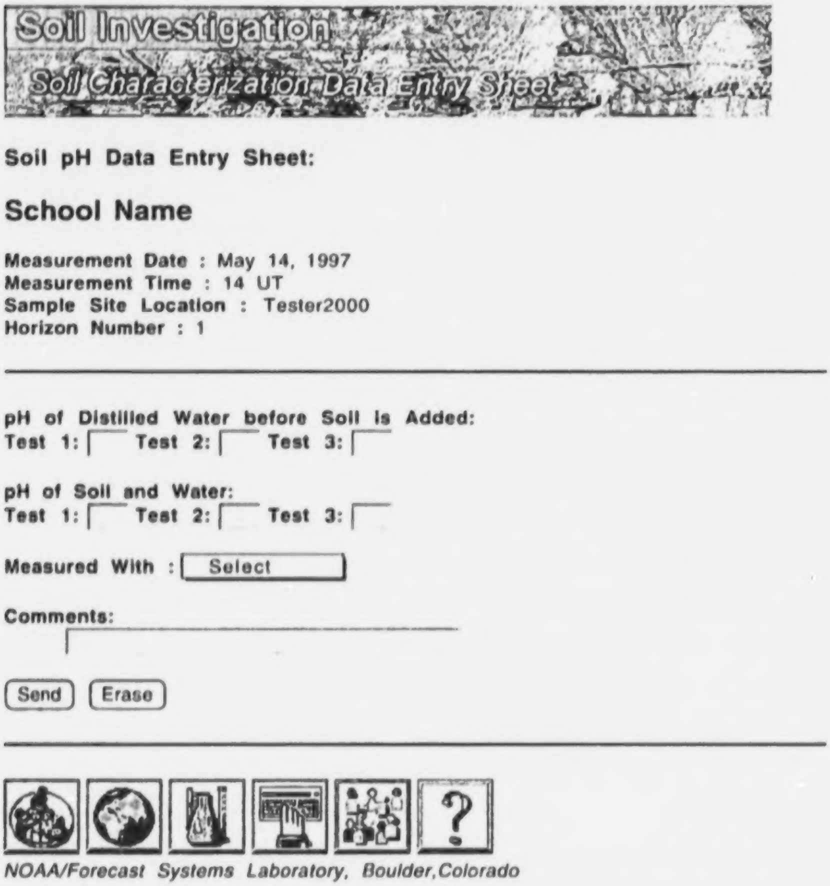

Soil Investigation

Soil Characterization Data Entry Sheet

Soil pH Data Entry Sheet:

School Name

Measurement Date : May 14, 1997
Measurement Time : 14 UT
Sample Site Location : Tester2000
Horizon Number : 1

pH of Distilled Water before Soil is Added:
Test 1: ☐ **Test 2:** ☐ **Test 3:** ☐

pH of Soil and Water:
Test 1: ☐ **Test 2:** ☐ **Test 3:** ☐

Measured With : Select

Comments:

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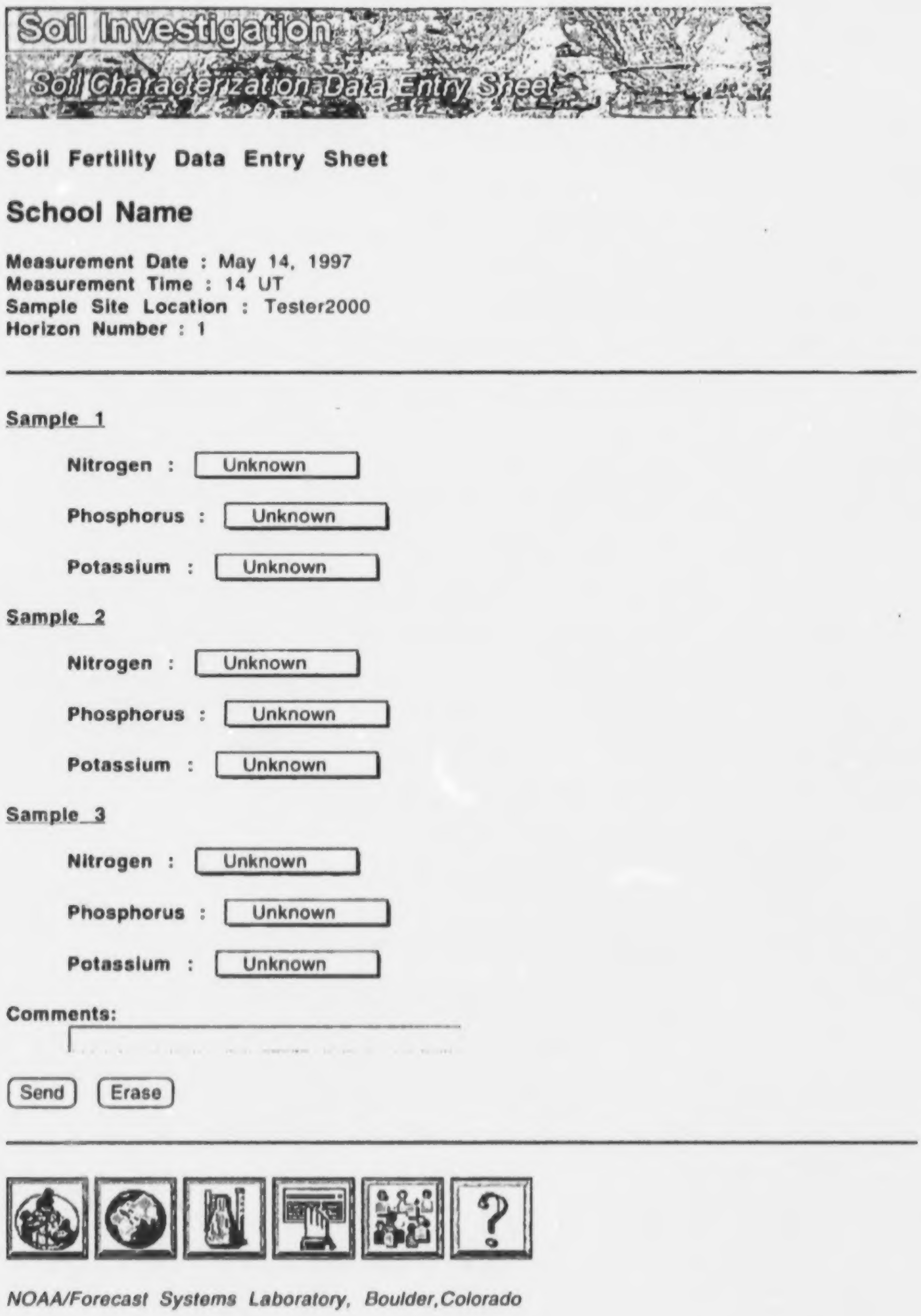
Soil Investigation
Soil Characterization Data Entry Sheet

Soil Fertility Data Entry Sheet

School Name

Measurement Date : May 14, 1997
Measurement Time : 14 UT
Sample Site Location : Tester2000
Horizon Number : 1

Sample 1

Nitrogen : Unknown
Phosphorus : Unknown
Potassium : Unknown

Sample 2

Nitrogen : Unknown
Phosphorus : Unknown
Potassium : Unknown

Sample 3

Nitrogen : Unknown
Phosphorus : Unknown
Potassium : Unknown

Comments:

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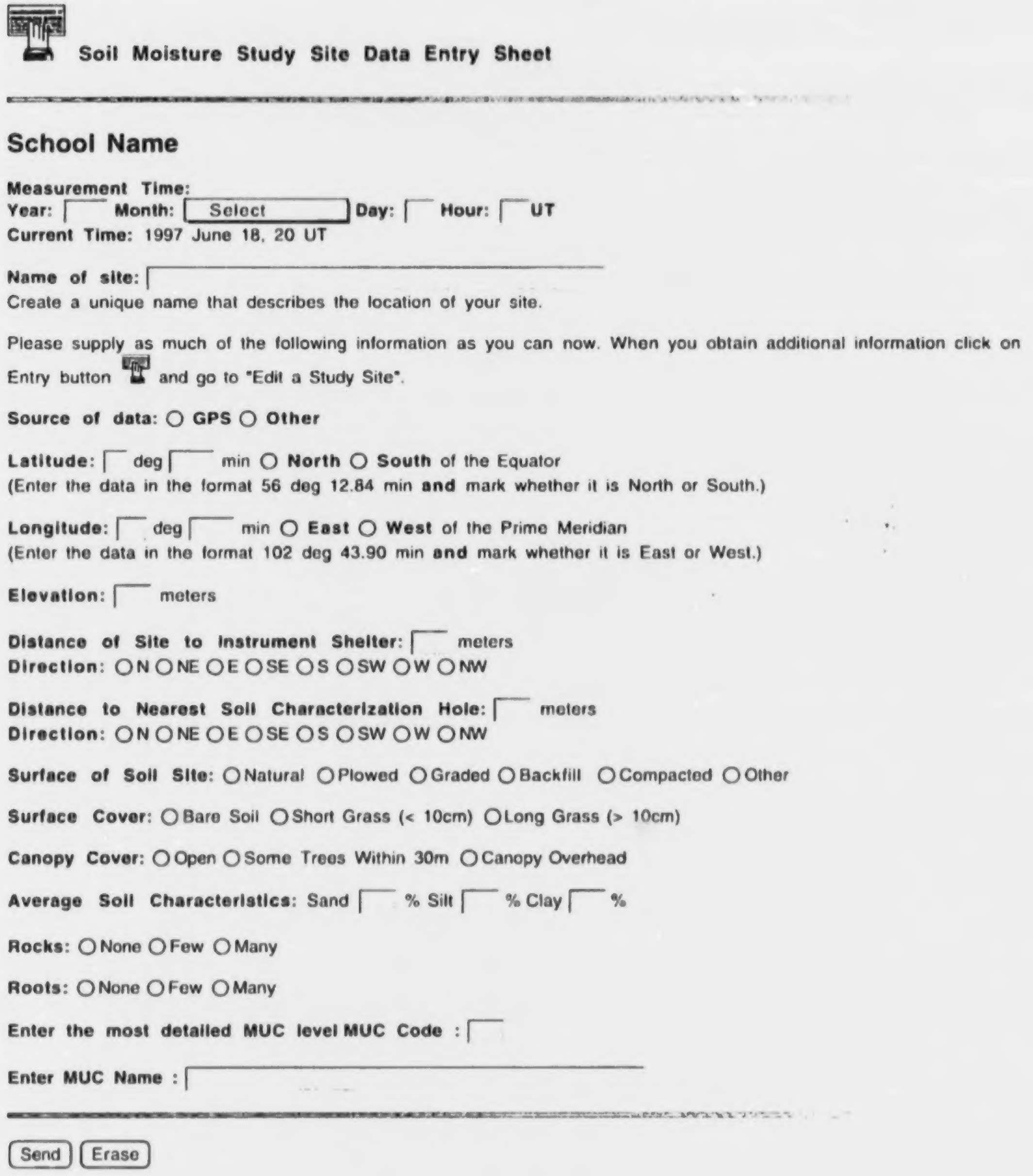
Soil Investigation



Soil Moisture Study Site Data Entry Sheet

School Name

Measurement Time:
Year: ☐ **Month:** [Select] **Day:** ☐ **Hour:** ☐ **UT**
Current Time: 1997 June 18, 20 UT

Name of site: ☐
Create a unique name that describes the location of your site.

Please supply as much of the following information as you can now. When you obtain additional information click on Entry button and go to "Edit a Study Site".

Source of data: ○ **GPS** ○ **Other**

Latitude: ☐ deg ☐ min ○ **North** ○ **South** of the Equator
(Enter the data in the format 56 deg 12.84 min **and** mark whether it is North or South.)

Longitude: ☐ deg ☐ min ○ **East** ○ **West** of the Prime Meridian
(Enter the data in the format 102 deg 43.90 min **and** mark whether it is East or West.)

Elevation: ☐ meters

Distance of Site to Instrument Shelter: ☐ meters
Direction: ○ N ○ NE ○ E ○ SE ○ S ○ SW ○ W ○ NW

Distance to Nearest Soil Characterization Hole: ☐ meters
Direction: ○ N ○ NE ○ E ○ SE ○ S ○ SW ○ W ○ NW

Surface of Soil Site: ○ Natural ○ Plowed ○ Graded ○ Backfill ○ Compacted ○ Other

Surface Cover: ○ Bare Soil ○ Short Grass (< 10cm) ○ Long Grass (> 10cm)

Canopy Cover: ○ Open ○ Some Trees Within 30m ○ Canopy Overhead

Average Soil Characteristics: Sand ☐ % Silt ☐ % Clay ☐ %

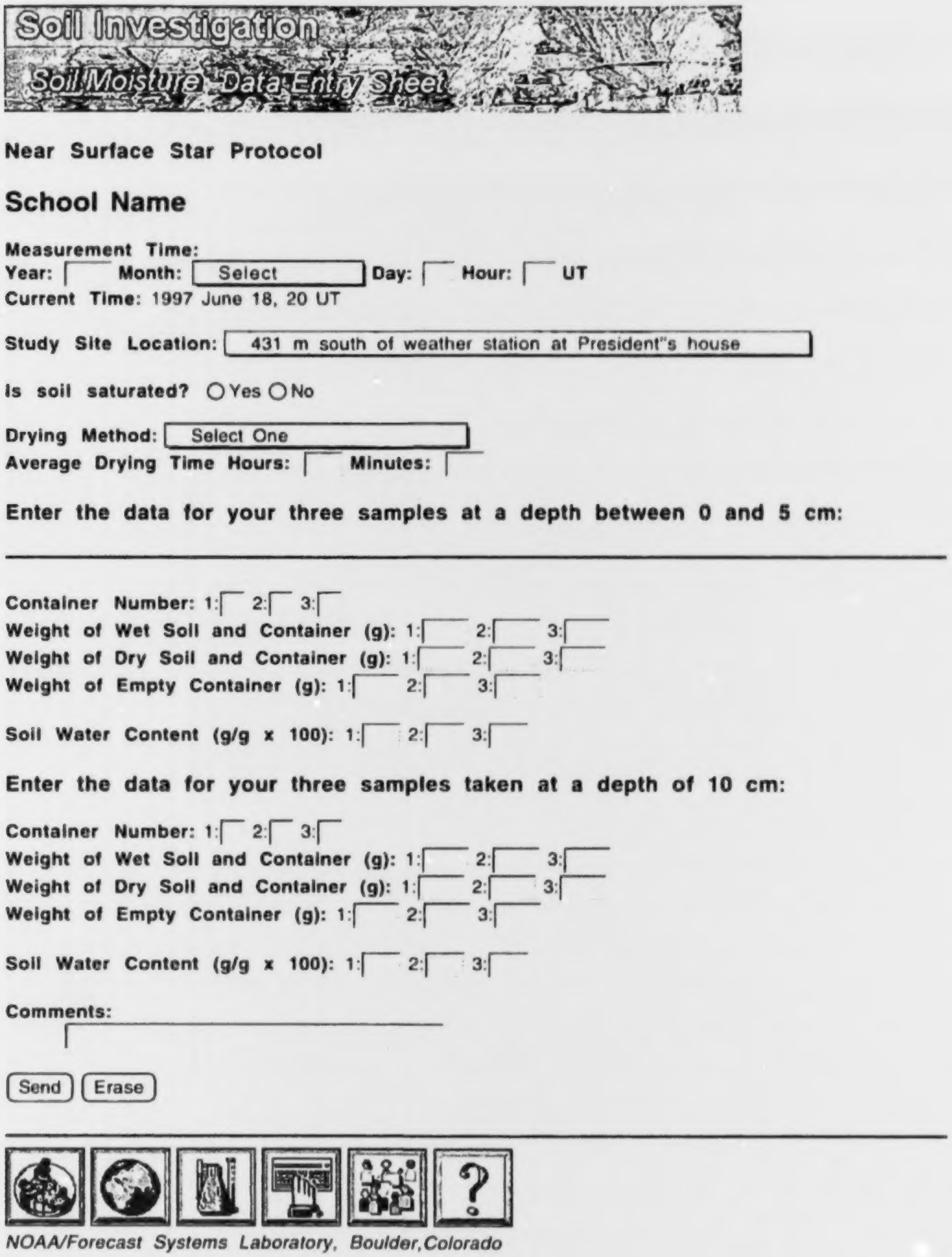
Rocks: ○ None ○ Few ○ Many

Roots: ○ None ○ Few ○ Many

Enter the most detailed MUC level MUC Code : ☐

Enter MUC Name : ☐

[Send] [Erase]



Soil Investigation

Soil Moisture Data Entry Sheet

Near Surface Star Protocol

School Name

Measurement Time:

Year: ☐ **Month:** [Select] **Day:** ☐ **Hour:** ☐ **UT**

Current Time: 1997 June 18, 20 UT

Study Site Location: [431 m south of weather station at President"s house]

Is soil saturated? ○ Yes ○ No

Drying Method: [Select One]

Average Drying Time Hours: ☐ **Minutes:** ☐

Enter the data for your three samples at a depth between 0 and 5 cm:

Container Number: 1: ☐ 2: ☐ 3: ☐

Weight of Wet Soil and Container (g): 1: ☐ 2: ☐ 3: ☐

Weight of Dry Soil and Container (g): 1: ☐ 2: ☐ 3: ☐

Weight of Empty Container (g): 1: ☐ 2: ☐ 3: ☐

Soil Water Content (g/g x 100): 1: ☐ 2: ☐ 3: ☐

Enter the data for your three samples taken at a depth of 10 cm:

Container Number: 1: ☐ 2: ☐ 3: ☐

Weight of Wet Soil and Container (g): 1: ☐ 2: ☐ 3: ☐

Weight of Dry Soil and Container (g): 1: ☐ 2: ☐ 3: ☐

Weight of Empty Container (g): 1: ☐ 2: ☐ 3: ☐

Soil Water Content (g/g x 100): 1: ☐ 2: ☐ 3: ☐

Comments:

☐

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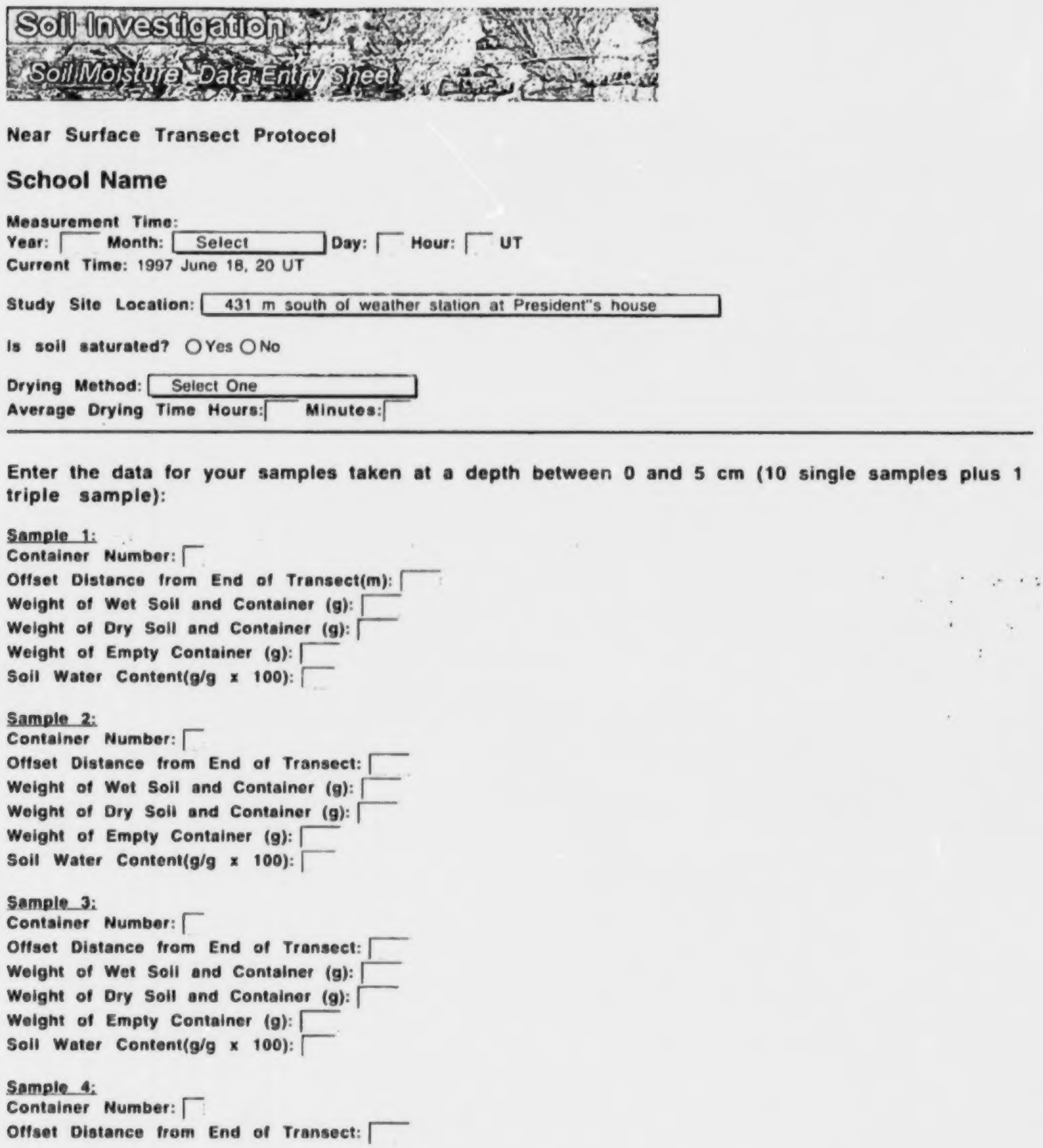

Soil Investigation

Soil Moisture Data Entry Sheet

Near Surface Transect Protocol

School Name

Measurement Time:
Year: **Month:** Select **Day:** **Hour:** UT
Current Time: 1997 June 18, 20 UT

Study Site Location: 431 m south of weather station at President"s house

Is soil saturated? ○ Yes ○ No

Drying Method: Select One
Average Drying Time Hours: **Minutes:**

Enter the data for your samples taken at a depth between 0 and 5 cm (10 single samples plus 1 triple sample):

Sample 1:
Container Number:
Offset Distance from End of Transect(m):
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 2:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 3:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 4:
Container Number:
Offset Distance from End of Transect:

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Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 5:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 6:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 7:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 8:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 9:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 10:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):

Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 11:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 12:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content(g/g x 100):

Sample 13:
Container Number:
Offset Distance from End of Transect:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content (g/g x 100):

Comments:

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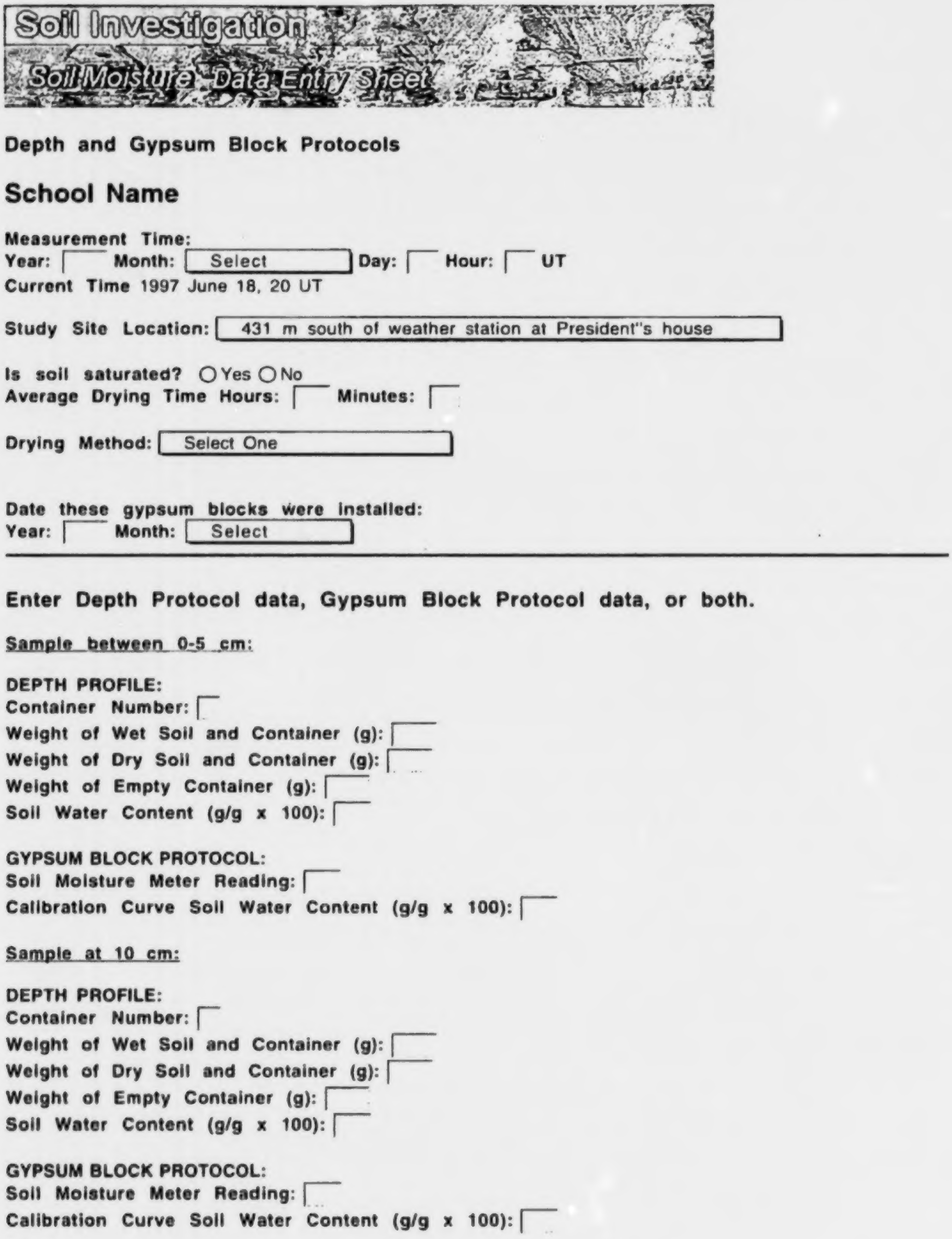

Soil Investigation

Soil Moisture Data Entry Sheet

Depth and Gypsum Block Protocols

School Name

Measurement Time:
Year: ☐ **Month:** Select **Day:** ☐ **Hour:** ☐ **UT**
Current Time 1997 June 18, 20 UT

Study Site Location: 431 m south of weather station at President''s house

Is soil saturated? ○ Yes ○ No
Average Drying Time Hours: ☐ **Minutes:** ☐

Drying Method: Select One

Date these gypsum blocks were installed:
Year: ☐ **Month:** Select

Enter Depth Protocol data, Gypsum Block Protocol data, or both.

Sample between 0-5 cm:

DEPTH PROFILE:
Container Number: ☐
Weight of Wet Soil and Container (g): ☐
Weight of Dry Soil and Container (g): ☐
Weight of Empty Container (g): ☐
Soil Water Content (g/g x 100): ☐

GYPSUM BLOCK PROTOCOL:
Soil Moisture Meter Reading: ☐
Calibration Curve Soil Water Content (g/g x 100): ☐

Sample at 10 cm:

DEPTH PROFILE:
Container Number: ☐
Weight of Wet Soil and Container (g): ☐
Weight of Dry Soil and Container (g): ☐
Weight of Empty Container (g): ☐
Soil Water Content (g/g x 100): ☐

GYPSUM BLOCK PROTOCOL:
Soil Moisture Meter Reading: ☐
Calibration Curve Soil Water Content (g/g x 100): ☐

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Sample at 30 cm:

DEPTH PROFILE:
Container Number:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content (g/g x 100):

GYPSUM BLOCK PROTOCOL:
Soil Moisture Meter Reading:
Calibration Curve Soil Water Content (g/g x 100):

Sample at 60 cm:

DEPTH PROFILE:
Container Number:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content (g/g x 100):

GYPSUM BLOCK PROTOCOL:
Soil Moisture Meter Reading:
Calibration Curve Soil Water Content (g/g x 100):

Sample at 90 cm:

DEPTH PROFILE:
Container Number:
Weight of Wet Soil and Container (g):
Weight of Dry Soil and Container (g):
Weight of Empty Container (g):
Soil Water Content (g/g x 100):

GYPSUM BLOCK PROTOCOL:
Soil Moisture Meter Reading:
Calibration Curve Soil Water Content (g/g x 100):

Comments:

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Soil Investigation

Soil Temperature Data Entry Sheet

School Name

Measurement Time:
Year: ☐ **Month:** Select **Day:** ☐ **Hour:** Enter hour below
Current Time: 1997 June 18, 20 UT

Study Site Location: SM43 1 m south of weather station at President"s house (Soil Mois. Site)

Enter all soil temperature data recorded in one day:

Soil Thermometer: Select

Has there been rain within the last 24 hours? ○ Yes ○ No

Sample 1:
Hour of Measurement (UT): ☐ **Minutes:** 0
Temperature at 5 cm: ☐ degrees C
Temperature at 10 cm: ☐ degrees C

Sample 2:
Hour of Measurement (UT): ☐ **Minutes:** 0
Temperature at 5 cm: ☐ degrees C
Temperature at 10 cm: ☐ degrees C

Sample 3:
Hour of Measurement (UT): ☐ **Minutes:** 0
Temperature at 5 cm: ☐ degrees C
Temperature at 10 cm: ☐ degrees C

Sample 4:
Hour of Measurement (UT): ☐ **Minutes:** 0
Temperature at 5 cm: ☐ degrees C
Temperature at 10 cm: ☐ degrees C

Sample 5:
Hour of Measurement (UT): ☐ **Minutes:** 0
Temperature at 5 cm: ☐ degrees C
Temperature at 10 cm: ☐ degrees C

Sample 6:
Hour of Measurement (UT): ☐ **Minutes:** 0
Temperature at 5 cm: ☐ degrees C
Temperature at 10 cm: ☐ degrees C

Sample 7:

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Hour of Measurement (UT): **Minutes:** 0
Temperature at 5 cm: degrees C
Temperature at 10 cm: degrees C

Sample 8:
Hour of Measurement (UT): **Minutes:** 0
Temperature at 5 cm: degrees C
Temperature at 10 cm: degrees C

Sample 9:
Hour of Measurement (UT): **Minutes:** 0
Temperature at 5 cm: degrees C
Temperature at 10 cm: degrees C

Sample 10:
Hour of Measurement (UT): **Minutes:** 0
Temperature at 5 cm: degrees C
Temperature at 10 cm: degrees C

Sample 11:
Hour of Measurement (UT): **Minutes:** 0
Temperature at 5 cm: degrees C
Temperature at 10 cm: degrees C

Comments:

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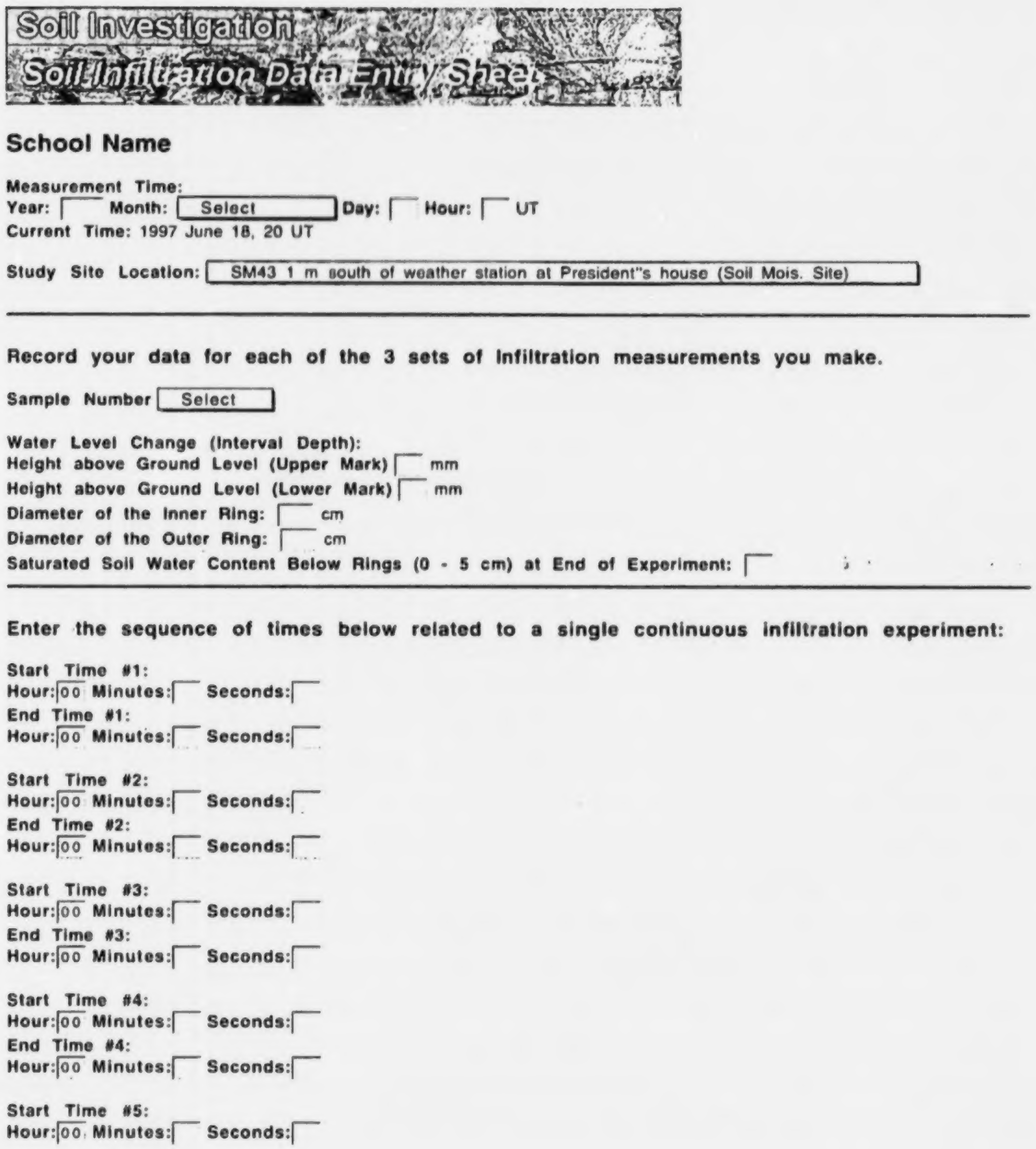

Soil Investigation

Soil Infiltration Data Entry Sheet

School Name

Measurement Time:
Year: **Month:** Select **Day:** **Hour:** UT
Current Time: 1997 June 18, 20 UT

Study Site Location: SM43 1 m south of weather station at President"s house (Soil Mois. Site)

Record your data for each of the 3 sets of infiltration measurements you make.

Sample Number Select

Water Level Change (Interval Depth):
Height above Ground Level (Upper Mark) mm
Height above Ground Level (Lower Mark) mm
Diameter of the Inner Ring: cm
Diameter of the Outer Ring: cm
Saturated Soil Water Content Below Rings (0 - 5 cm) at End of Experiment:

Enter the sequence of times below related to a single continuous infiltration experiment:

Start Time #1:
Hour: 00 **Minutes:** **Seconds:**
End Time #1:
Hour: 00 **Minutes:** **Seconds:**

Start Time #2:
Hour: 00 **Minutes:** **Seconds:**
End Time #2:
Hour: 00 **Minutes:** **Seconds:**

Start Time #3:
Hour: 00 **Minutes:** **Seconds:**
End Time #3:
Hour: 00 **Minutes:** **Seconds:**

Start Time #4:
Hour: 00 **Minutes:** **Seconds:**
End Time #4:
Hour: 00 **Minutes:** **Seconds:**

Start Time #5:
Hour: 00 **Minutes:** **Seconds:**

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End Time #5:
Hour: 00 **Minutes:** **Seconds:**

Start Time #6:
Hour: 00 **Minutes:** **Seconds:**
End Time #6:
Hour: 00 **Minutes:** **Seconds:**

Start Time #7:
Hour: 00 **Minutes:** **Seconds:**
End Time #7:
Hour: 00 **Minutes:** **Seconds:**

Start Time #8:
Hour: 00 **Minutes:** **Seconds:**
End Time #8:
Hour: 00 **Minutes:** **Seconds:**

Start Time #9:
Hour: 00 **Minutes:** **Seconds:**
End Time #9:
Hour: 00 **Minutes:** **Seconds:**

Comments:

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Land Cover/Biology Investigation

A GLOBE™ Learning Investigation

Land Cover/Biology Investigation at a Glance

Protocols

Identify the general land cover type to MUC level 1

Qualitative Land Cover Sample Site Protocol
- Data collected once for each land cover sample:
  - GPS location, photos of sample, determine MUC class

Quantitative Land Cover Sample Site Protocol
- Data collected once for each land cover sample:
  - GPS location, photos of sample, biometry measurements, determine MUC class

Biometry Protocol
- Data collected once or twice per year for Biology Study Site, once for the Quantitative Land Cover Sample Sites
  - Determine dominant and co-dominant vegetation types
  - Biometry measurements: tree height and circumference, grass biomass, canopy cover, and ground cover

MUC System Protocol

Manual Interpretation Land Cover Mapping Protocol

Unsupervised Clustering Land Cover Mapping Protocol

Accuracy Assessment Protocol
- Create a difference/error matrix, calculate overall accuracy and interpret results.

Suggested Sequence of Activities

[Certain Learning Activities are desirable prior to implementing Protocols]

Read *Remote Sensing* found in the *Implementation Guide*

Read the *Scientists' Letter* and *Interview* with your students

Select a site and identify the general land cover type to MUC level 1

Perform *Qualitative* or *Quantitative Land Cover Sample Site Protocols*

Pre-Protocol Learning Activity: *Site Seeing*–introduces systems concepts

Perform *Biometry Protocol*, set up Biology Study Site

Pre-Protocol Learning Activity: *Leaf Classification* introduces the concepts of classification

Perform *MUC System Protocol*

Pre-Protocol Learning Activities: *Odyssey of the Eyes*; introduces remote sensing and *Some Like It Hot* introduces false-color images

Tutorial: *Manual Interpretation* from *Toolkit*

Tutorials: *Introduction to MultiSpec* and *Unsupervised Clustering Tutorial* if you will be doing computer image processing

Perform either *Manual Interpretation Land Cover Mapping Protocol* or *Unsupervised Clustering Land Cover Mapping Protocol*

Post-Protocol Learning Activity: *Discovery Area*–using images students create

Pre-Protocol Learning Activity: *Introducing the Difference/Error Matrix or What's the Difference?*

Perform *Accuracy Assessment Protocol*

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Scientists' Letter

GLOBE Teachers:

Hello and welcome to the new Land Cover and Biology research materials! Actually, they are not entirely new – GLOBE teachers and students have been doing biometry in their "pixel" study sites since the beginning of the program. Some classes have also been interpreting satellite images of their local area, although this wasn't a formal "protocol" until now. What we have attempted in this new set of materials is to tie together biometry measurements with observations of cover type in a number of ground sites, and with land cover mapping of your area using the satellite imagery provided to you by GLOBE. In the process, we have added biometry protocols for grasslands in addition to trees, and procedures for evaluating the accuracy of land cover maps – an important aspect of the science of remote sensing and global monitoring. We have also adopted and modified a new classification system for land cover which we hope will be more comprehensive than the system used previously. The goal is to involve you and your students in all phases of our research in remote sensing and land cover mapping at the University of New Hampshire. Please let us know how we are doing, and what you think of the new materials.

Best Regards,

The Land Cover/Biology Co-Principal Investigators:

David S. Bartlett	Russell G. Congalton	Janet W. Campbell
David S. Bartlett, PhD	Russell G. Congalton, PhD	Janet W. Campbell, PhD
Eleanor Abrams	Mimi L. Becker	
Eleanor Abrams, PhD	Mimi L. Becker, PhD	

Meet the Land Cover/ Biology Team

Duplicate and distribute to students

This section represents a combined effort between the Biometry and Accuracy Assessment teams at the University of New Hampshire to form the Land Cover Investigation. Dr. Russell Congalton is the science Principal Investigator and Dr. Mimi Becker is the education Principal Investigator for the Accuracy Assessment Team. Dr. David Bartlett is the science Principal Investigator and Dr. Eleanor Abrams is the education Principal Investigator for the Biometry team. Mr. Gary Lauten is a project scientist with the Biometry team. This interview is with these members of the Land Cover Investigation.

Dr. Congalton: I deal with satellite data, aerial photography, and remote sensing or mapping land cover pretty much all over the world. My degrees are in forestry. People don't think of forestry as a science, but it's very science-based and interdisciplinary. You need physics, computers, biology, statistics and math in order to put it together.

GLOBE: *When I think forestry, I think being out there in the forest—*

Dr. Congalton: —and playing chess with Smokey the Bear.

GLOBE: *And being in a tower overlooking the wilderness. Now you're at a university. What was your image of forestry back then?*

Dr. Congalton: It wasn't Smokey the Bear. I never thought that I would live in the middle of nowhere and wash my clothes in a stream. I still get to go to the woods on a regular basis. I like being in the office when it's raining or snowing. I like playing on the computer.

GLOBE: *Do you spend time in a laboratory?*

Dr. Congalton: My laboratory is the computer laboratory. The computers allow us to do statistical analyses as well as manipulation of the satellite data, the aerial photography, for our mapping purposes.

GLOBE: *Is most of the information you're working with from the sky?*

Dr. Congalton: Yes, but we need to verify the satellite data with what's happening on the ground. There are some things you can't tell from satellite data, like a species of plant that's too small for satellite photographs to capture. We want to validate the maps made from remotely-sensed data over the last few years so we can see what's changing on the Earth. We've never determined how good the satellite data or photography is for a lot of areas. We need to know how good the remotely-sensed satellite data is in order to verify the decisions we make based on this data.

GLOBE: *What kind of decisions?*

Dr. Congalton: There are many estimates of land cover in the Amazon. There's actually never been an accurate assessment of this. People publish figures saying, "X amount of trees are being cut a day," but there's never been an accuracy assessment to determine if that's really true.

Dr. Bartlett: We're using computer models and our knowledge of, for example, how plants utilize sunlight, water and nutrients in order to simulate and ultimately predict the behavior of ecosystems. GLOBE students can help. In trying to replicate conditions of a particular area, for example, you need to know what kind of vegetation is there and its environmental conditions. The GLOBE data provides that information. GLOBE is also important for validation. Validating models is a process of running the model and comparing the results to measurements in the real world.

GLOBE: *By modeling, we're talking about predicting the future given certain parameters?*

Dr. Bartlett: Predicting change. What if I change the average annual temperature by five degrees? Or reduce the average annual precipitation in this region by 50 centimeters? Put that into the model and see what it predicts. That's the real power of modeling, but it relies on comparing the output to real data, and the only real data we currently have is from our limited resources and the data from students.

GLOBE: *What is remotely-sensed data?*

Dr. Bartlett: In the context of GLOBE, we're primarily talking about satellite data. Satellites have an advantage in that they collect data for long periods of time. This is what is needed for global environmental monitoring.

GLOBE: *What is the satellite actually seeing or measuring? Can it detect vegetation? "Hey, that's green. That must be grass?"*

Mr. Lauten: A satellite doesn't know what it sees. All it sees is a brightness from a portion of the ground. Landsat sees visible plus near infrared and middle infrared radiation. Essentially it can see what your eyes see, as well as the near infrared and middle infrared.

GLOBE: *Have students ever helped verify satellite data?*

Dr. Congalton: Not that I know of. And certainly not at GLOBE's scale.

GLOBE: *A common perception of scientists is they're lone-wolf types working in their laboratories late at night. But that doesn't seem to be the case here. Here it's collaborative. Why is that?*

Dr. Becker: We're dealing with complex systems at the global and local levels. Most of the work we do is interdisciplinary, so we have to work together to solve problems.

Dr. Bartlett: GLOBE is a unique collaboration between science and science education. No one person can provide expertise in all the facets of world-class environmental science as well as science concepts for young students. It's common for people in our line of work to work with scientists in other disciplines.

GLOBE: *What question are you trying to answer with the GLOBE data?*

Dr. Bartlett: How the Earth as a whole system works. However, the Earth is very complex. One way to simplify that problem is to look for processes that link those diverse parts of the system. For example, there are a small number of important materials, compounds and nutrients that living things in one way or another need and use during their lifetimes. Those include water, carbon, nitrogen, sulfur, sunlight. All plants, whether they be in arid environments or tropical environments, need some combination of those to exist. So we investigate the cycling of those materials to try to produce a picture of how vegetation operates. And although it can't do everything, remote sensing has a role to play in that.

Dr. Becker: As a policy scientist, I'm concerned with how people relate to the ecosystem. How can we maintain healthy regional and global systems in the face of continuing human stress? Where we have severely impaired systems, are there ways we can constrain human behavior so that basic ecological functions are restored? What kinds of decisions does that involve? What kind of information do we need to change policy and educate people?

GLOBE: *You are a policy scientist?*

Dr. Becker: I'm a natural-resource and environmental-policy scientist, so I'm interested in relationships between humans and their communities, and the Earth systems that support them.

GLOBE: *As a woman, what were your attitudes toward science when you were in middle school and high school?*

Dr. Becker: They evolved. I came through a period of time when women were not expected to do either science or math. I still have a certain amount of math phobia, although I can do it when I have to. My father was a photographer and I fooled around with chemicals and worked in darkrooms.

GLOBE: *What are you going to do with your findings?*

Dr. Becker: For example, there are issues that relate to water shortages or land-use activities. The only way they're going to get solved is locally. So I'll be looking to collaborate with students in those areas where I know problems exist. We'll try to understand what's going on and how that's related to the local policy and management. My interest is in training people how to research so they can acquire information, interpret it, and apply it to problem-solving at the level of their own regions or watersheds.

GLOBE: *When you talk about acting locally, do you mean talking to local scientists? Governments? Businesses?*

Dr. Becker: One way that we have begun to solve some serious problems is to link the scientists, the regulators, the polluters and the

people who have a stake in healthy living in the bioregion. There are GLOBE students who are sitting down with people in their communities and saying, "Look, we have a problem. How can we work together to solve it?" So I look at how the system works, what people need to know and how can they get that information to solve the problem.

GLOBE: *Is science at the root of this kind of change?*

Dr. Becker: Absolutely. Science is where you start to understand the problem. You have to get at its causes and effects, and then assess how to address it. Science is essential as a systematic approach to the acquisition of information and its evaluation.

GLOBE: *How does science acquire this information?*

Dr. Bartlett: One way is to set up networks of data collection. To give you an example, back in the 1950s, when David Keeling set up a monitoring station for carbon dioxide concentrations in the atmosphere in Mauna Lau, Hawaii, nobody had any idea that we had already begun to affect global atmospheric carbon dioxide concentrations. It was only after 15 or 20 years of data collection that people began to see this clear trend of increasing CO_2 levels. With GLOBE sites, we may well be able to identify trends.

Dr. Bartlett: One way GLOBE will be influential is by educating the students who will someday be policy makers. They will be the politicians who will hopefully make better-educated decisions than are currently being made because they've been introduced to science; they've studied their own environments; they've taken these measurements; and they know how the data is interrelated. I think they will have a much better understanding than we did when we were kids.

Introduction

The Big Picture

The type and amount of land cover in an area are important characteristics from the standpoint of understanding the Earth as a system - the cycles of energy, water, and chemical elements essential to life such as carbon, nitrogen, sulfur, and phosphorous. In the energy cycle, land cover influences the reflection of solar radiation from the land surface. This in turn influences the heating of the atmosphere and local and regional climate patterns. The resulting patterns in atmospheric temperature influence the kinds of plants that can live in an area and this largely determines the type of natural land cover. In the water and biogeochemical cycles, variations in the type and amount of land cover influence the cycling of water, carbon, nitrogen, and sulfur among the soil, plants and atmosphere.

Since the mid-1980's, an area of research known as Earth system science has developed to study and understand these processes and the interactions among the atmosphere, *hydrosphere*, *biosphere*, *geosphere*, and *cryosphere*. GLOBE students will be mapping land cover and providing ground observations which will advance their own understanding of the landscape around them as well as the research of Earth system scientists. This mapping involves distinguishing the types, or classes, of cover on the surface.

There are many systems for classifying land use. In GLOBE, we use an adaptation of the international system used by the United Nations which we call the Modified UNESCO Classification (MUC) system. See Tables LAND-P-3 and LAND-P-4.

Identification of the various land cover classes in an area can be done in a number of ways. In studying large areas, satellite data sets are common sources of images of land surface characteristics used to make land cover maps. However, simply examining an image without some specific knowledge of the area involved may reveal little about what the actual land cover is. The best and most accurate source of information on the kinds of land cover comes from visiting the site and conducting a detailed assessment of its characteristics on the ground. The data gathered by your students from such visits constitute an important source of information about the land cover within your 15 km x 15 km GLOBE Study Site. In particular, the detailed data acquired from 90 m x 90 m Land Cover Sample Sites will contribute to a better understanding of the *biomass*, the land cover, and the amount of photosynthesis taking place in your part of the world.

Natural vegetation is so important to the myriad processes and cycles of interest to Earth system scientists that you will be conducting several detailed measurements in some of the ground sites which are dominated by vegetation. These measurements are referred to as *biometry* and they quantify the size and extent of the plants in these sites. This is important information for a variety of reasons:

1. Although humans have extensively modified and replaced natural vegetation, most of the Earth's land surface is still covered by the naturally vegetated ecosystems which evolved in response to local geographical and climatic conditions. The type and nature of the vegetation present therefore tells us a great deal about other environmental variables such as rainfall or temperature.
2. Terrestrial vegetation is a major component of the large system we call Earth. Plants absorb and cycle nutrients - carbon dioxide, nitrogen, sulfur and phosphorus from the atmosphere and soil. They absorb water from the soil, incorporating it into their tissues, and *transpiring* some of it to the atmosphere. Plants also form the basic foundation of the food chains which support other life forms.

3. Vegetation can be a sensitive indicator of change in local or regional environments. Subtle changes in climate or other environmental factors may reveal themselves first as changes in the type or growth of local vegetation.

4. Human-induced changes in vegetation affect not only the plants themselves, but all the important cycles of nutrients and water in which vegetation plays so important a role. To understand the changes taking place in the Earth system, the human-induced and natural changes in land cover must be tracked.

5. Because of the importance of vegetation, the land-oriented satellite sensor (Thematic Mapper) you will use for mapping is designed specifically to identify and discriminate various kinds of vegetation. In addition, recent research has shown that satellite data are sensitive to the amount and health of many types of vegetation, but ground observations are needed to quantify and calibrate these relationships.

For all of these reasons, Earth system scientists are eager to have your maps, and your detailed biometric observations of naturally vegetated ground sites. Your data will tell us how important factors in the Earth system may be changing over time and how sensitive or resilient ecosystems are in the face of environmental change, and will improve our ability to interpret the satellite imagery we rely on to monitor large areas of the Earth's land surface.

Your field observations fill a major gap in scientists' ability to understand our planet because, even with your help, it is virtually impossible to visit the number of sites and collect all the data that we need. There is simply not enough time, money, or energy to get to enough sites. Therefore, the use of remotely sensed data (information collected from photography and satellite imagery) is critical to acquiring all the knowledge we need to understand the Earth as a system. Remotely sensed data can quickly and efficiently cover the entire Earth. As a GLOBE school you are given satellite imagery of a relatively large area compared to your school size. It would be very time-consuming and difficult for you to visit every area in your 15 km x 15 km GLOBE Study Site and yet one Landsat satellite Thematic Mapper image easily covers your area and 100 more like it. Using the tools that are described in this protocol you will generate a land cover map of your entire GLOBE Study Site by manual interpretation and by use of a computer program called MultiSpec. From these land cover maps, using the MUC classification scheme, you and your students will learn much about the area around your school.

Does producing this land cover map take the place of visits to sites on the ground? Absolutely not! The ground data collection is critical to effective use of the remotely sensed information. In order to be able to make the land cover map from the remotely sensed data, it is necessary to have visited some sites on the ground so that you can accurately identify certain sites on the satellite image. Without this ground data it would be impossible to make an effective land cover map from the satellite imagery.

The second use of your ground data is verification of land cover maps. A vital consideration for every scientist is the confidence that she or he can place in data collected by others or by automated systems. Often this confidence is based on some statistical measure, and such is the case in evaluating land cover maps generated from remotely sensed data. In order to have some confidence in a land cover map and make decisions based upon it, it is critical that the map be tested to see how good it is. This validation process is performed by comparing sample areas on the map with actual site visits on the ground. This comparison is then summarized in a table, called a difference or error matrix, which shows how well the land cover map represents what is really on the ground. Without ground data it would not be possible to generate land cover maps from remotely sensed data nor could we validate them once they were created.

GLOBE Student Data as Input to Models

Research scientists will incorporate GLOBE student data into models used in on-going research projects. The long-term goal of their research projects is to understand the primary biogeochemical cycles of Planet Earth. The primary cycles to be studied include those of carbon, sulfur, nitrogen and water. The overall strategy is to use numerical models to study how these cycles function, both in natural systems, where perturbations in the environment are produced primarily by climate variability, and in systems where disturbances have been induced by human activities. Among the GLOBE measurements used as inputs for such models are:

- Land cover class (MUC)
- Maximum/minimum air temperature throughout the growing season
- Precipitation throughout the growing season
- Tree circumference at a height of 1.35 meters and how it changes over time
- Soil moisture throughout the growing season

By collecting data using the *Land Cover/Biology Protocols*, you and your students will become partners in this type of Earth system science research. The essence of a partnership is that each of the participants brings unique strengths which make the collaboration stronger. Your contribution is the intimate knowledge you have, and can obtain, of your local area. The Earth system scientists place that knowledge in the larger context of their models and efforts to understand our whole planet. Only by working together can we hope to know both the details and the integrated picture of the Earth system.

Student Learning Goals

There are two overarching concepts for this investigation. The first is systems, as examined by the sample site and biometry protocols. The sub-concepts involved are productivity, boundaries, inputs, outputs, cycles (seasons, feedback loops). Some of the processes are representative sampling, indirect and direct measurements, classification (using generalizations and choices), and drawing conclusions based upon evidence.

The second overarching concept is models, and is particularly important for the mapping and accuracy assessment protocols. Sub-concepts are representations of reality, symbolic representation, scale, perspectives, habitat, land use changes, and habitat fragmentation. Some of our processes are mapping, modeling, and validation.

Why Scientists Use Models

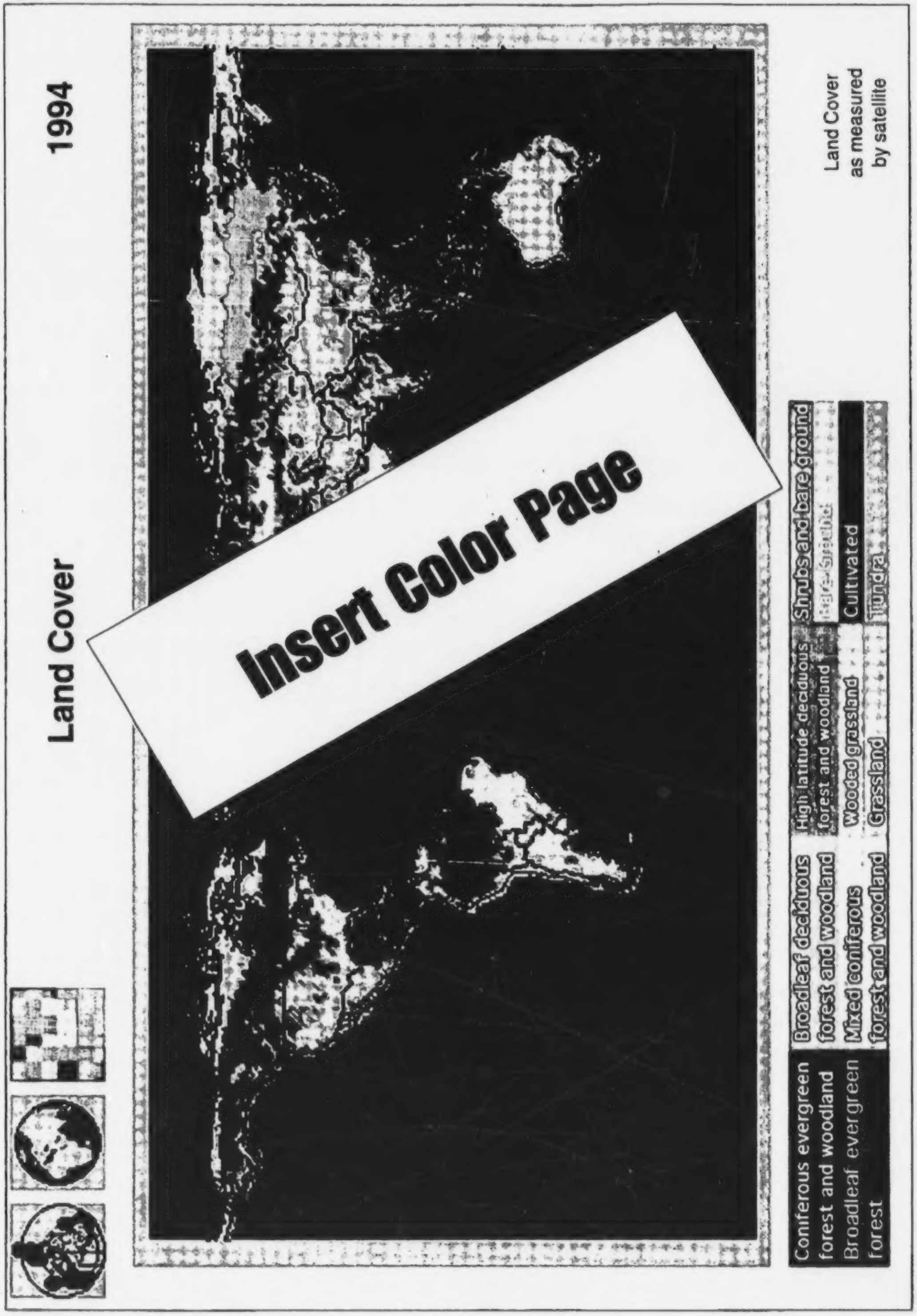
As children, we all played with toys. Toys are generally physical models which represent items that are important in the adult world and that are not available to children. Baby dolls, toy cars and trucks, stuffed animals, etc., are all examples of physical models that allowed us to use our imaginations to explore and better understand our childhood world. Conceptual or mathematical models are a tool used by scientists to explore and better understand processes or phenomena in the real world. There are several reasons why models are used.

One of the reasons is that models allow scientists to evaluate processes or phenomena that would be difficult to study in any other way. The study of the processes of photosynthesis and *evapotranspiration* is such an example. In both cases, the rate of each process is dependent on gas exchange at the stomates in leaves. Open stomates allow exchange of carbon dioxide (CO_2), oxygen (O_2) and water vapor, while closed stomates dramatically reduce such gas exchange. Measurement of small amounts of gas exchanged by a single leaf is possible using a device known as an *infrared gas analyzer*, but it is time consuming and only allows one leaf to be analyzed at a time. However, if light conditions are known (full sunlight causes stomates to open, while cloudy conditions lead to closed stomates in many plants), and the amount of recent rainfall (which governs the availability of water needed to open stomates) and maximum temperature (temperature influences the rate of diffusion of these gasses in or out of the open stomates) are known, a model can be developed which predicts gas exchange rates. If the amount of foliage is known, the photosynthetic rate and evapotranspiration rate for entire trees and/or forests can be modeled.

Another reason for using models is that in order to make a model which works well (the predicted results compare well with actual measured results) the developer of the model must really understand the process being modeled. Developing a model forces scientists to consider all of the input variables (such as CO_2, O_2 and water vapor, as well as temperature, available water, duration and intensity of sunlight, etc.) and the interrelationships among these variables. As a part of the process of developing a model, a more thorough understanding of the process being modeled results.

A third reason for using models relates to being able to modify the input parameters in order to predict realistic changes in output. This is an especially valuable aspect of using models when actual experimental manipulation of input variables is either impractical or impossible. Using the example of photosynthesis and evapotranspiration, a model allows scientists to study the effects of increasing atmospheric CO_2 and temperature on both photosynthetic activity (primary production) and return of water vapor (transpiration) to the atmosphere for forested sites. Such an experiment would be impractical to do in the field.

Figure LAND-I-1: Global Land Cover


Land Cover
1994
Land Cover as measured by satellite
Insert Color Page
Coniferous evergreen forest and woodland
Broadleaf evergreen forest
Broadleaf deciduous forest and woodland
Mixed coniferous forest and woodland
High latitude deciduous forest and woodland
Wooded grassland
Grassland
Shrubs and bare ground
Bare ground
Cultivated
Tundra

Source: GLOBE Home Page

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Protocols

How to Perform Your Land Cover/Biology Investigation

Qualitative Land Cover Sample Site Protocol

Students locate, photograph, and determine the MUC class for 90 m x 90 m areas of homogeneous land cover.

Quantitative Land Cover Sample Site Protocol

Students locate and photograph 90 m x 90 m areas of forest, woodland, or grassland, take measurements of the properties of the vegetation, and determine the MUC class.

Biometry Protocol

Students measure properties of vegetation and identify species.

MUC System Protocol

Students use the MUC System to classify land cover

Manual Interpretation Land Cover Mapping Protocol

Students delineate different areas of land cover as seen on their TM image.

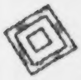
Unsupervised Clustering Land Cover Mapping Protocol

Students use MultiSpec to perform unsupervised clustering of their TM image and then assign MUC classes to every cluster to obtain a land cover map.

Accuracy Assessment Protocol

Students use observations of validation Land Cover Sample Sites to construct a difference/error matrix and determine the accuracy of their land cover maps.

How to Perform Your Land Cover/Biology Investigation



The goals of the Land Cover/Biology Investigation are threefold:

1. to take detailed measurements at selected sites within the entire GLOBE Study Site. These measurements are used by scientists to study vegetation growth and change and to verify maps made from remotely sensed data.
2. to make observations at many sub-areas within the entire study site. These observations are used by scientists, and can be used by you, to validate land cover maps generated from remotely sensed data.
3. to create a land cover map of your entire study area. This map will be used in learning more about your surroundings by making observations and measurements at selected sample locations. Upon competing this investigation, you will know a great deal about the environment surrounding your school and will be able to monitor change as it happens.

Study Sites for the Investigation

The Land Cover/Biology Investigation requires two different kinds of study sites. The first is called the GLOBE Study Site and is the 15 km x 15 km area, with your school near the center, for which satellite imagery is provided to you by GLOBE. By performing the protocols and learning activities associated with this investigation, you and your students will become intimately familiar with this part of our global environment. Together, you will create a land cover map of the entire area, make observations about many sub-areas, and take detailed measurements in some of these areas.

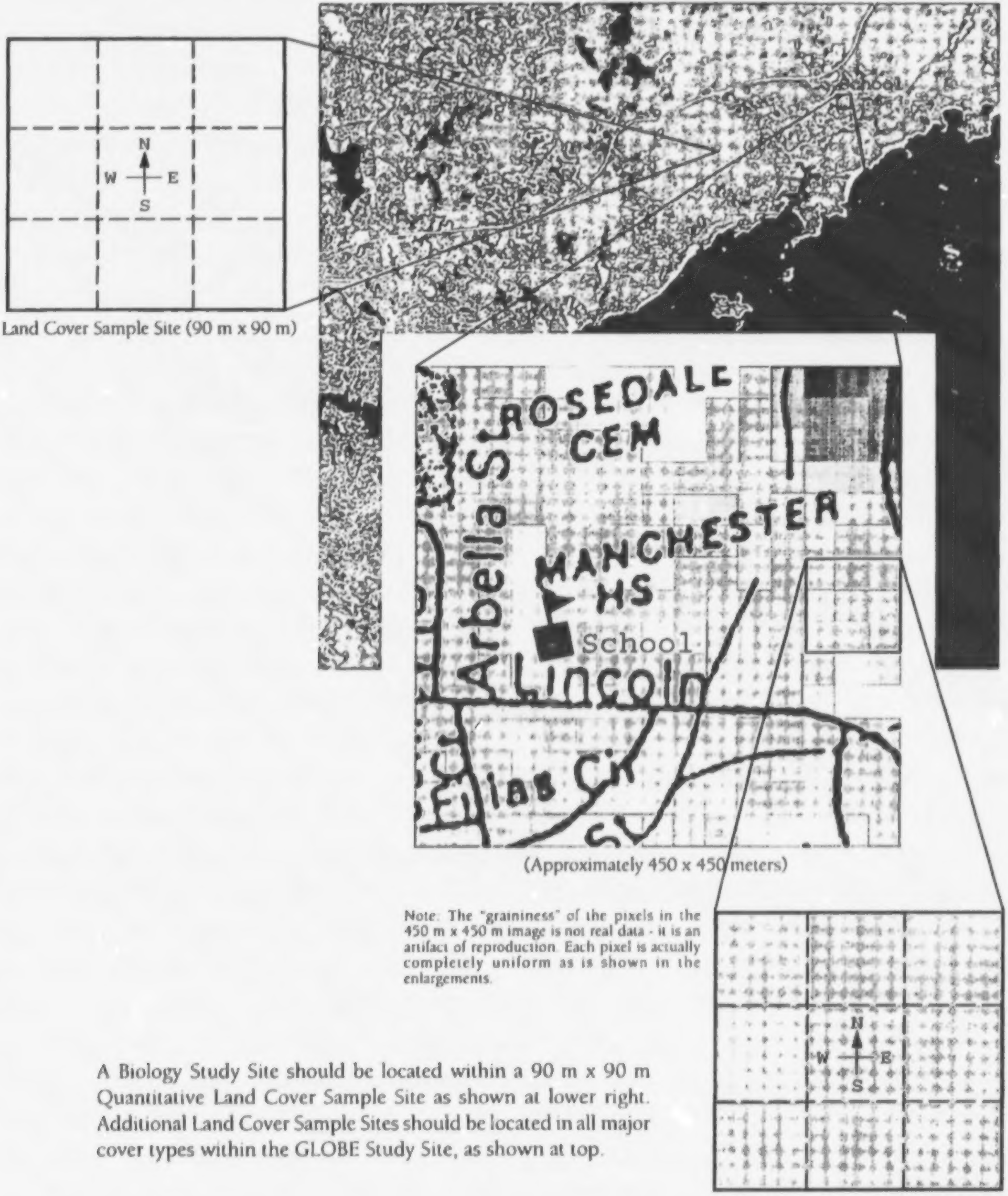
Within this GLOBE Study Site, it is important that you select appropriate ground sites (called Land Cover Sample Sites) for detailed measurements and observations. See Figure LAND-P-1. From an instructional standpoint, the goal of these Land Cover Sample Sites is to give your students a feel for the physical dimensions of *pixels* (picture elements) in the Landsat satellite Thematic Mapper images as well as providing a suitable and convenient site for class measurement activities within the GLOBE Study Site. For scientific purposes, a series of ground observations described later in this section need to be made in selected sample sites which are both representative of major types of land cover within your 15 km x 15 km study area, and large enough that they can be reliably located in satellite imagery.

Land Cover Sample Sites are areas of homogeneous land cover at least 90 m x 90 m in size. If the homogeneous area is larger than 90 m x 90 m, then the sample site is located toward the center of the area. See Figure LAND-P-3. An area 90 m x 90 m is necessary in order to accurately locate it on the ground and on the satellite imagery. This area is equivalent to 9 Landsat Thematic Mapper (TM) satellite pixels (a square of 3 pixels by 3 pixels). See the *Remote Sensing* section of the *Implementation Guide*.

There are two kinds of Land Cover Sample Sites - Qualitative and Quantitative. The latitude, longitude, and elevation of all Land Cover Sample Sites must be determined using a GPS (Global Positioning System) receiver, the land cover must be classified using the Modified UNESCO Classification (MUC) system, and the land cover must be documented in photographs taken from the middle of the site. The data for Qualitative Land Cover Sample Sites are easier to collect and require only these observations. Quantitative Land Cover Sample Sites require detailed measurements of the vegetation at the site and are only possible for certain land cover types. Qualitative and Quantitative Land Cover Sample Sites are visited only one time. However, within at least one Quantitative Land Cover Sample Site, each school should establish a permanent Biology Study Site. This site is used for obtaining long-term, periodic data related to vegetation growth. The Biology Study Site should be located in the center of a

Figure LAND-P-1: Land Cover Sites, Beverly, MA, USA as an example

GLOBE Study Site (15 x 15 kilometers)



Land Cover Sample Site (90 m x 90 m)

(Approximately 450 x 450 meters)

Note: The "graininess" of the pixels in the 450 m x 450 m image is not real data - it is an artifact of reproduction. Each pixel is actually completely uniform as is shown in the enlargements.

A Biology Study Site should be located within a 90 m x 90 m Quantitative Land Cover Sample Site as shown at lower right. Additional Land Cover Sample Sites should be located in all major cover types within the GLOBE Study Site, as shown at top.

A Biology Study Site (30 m x 30 m) within a Quantitative Land Cover Sample Site (90 m x 90 m)

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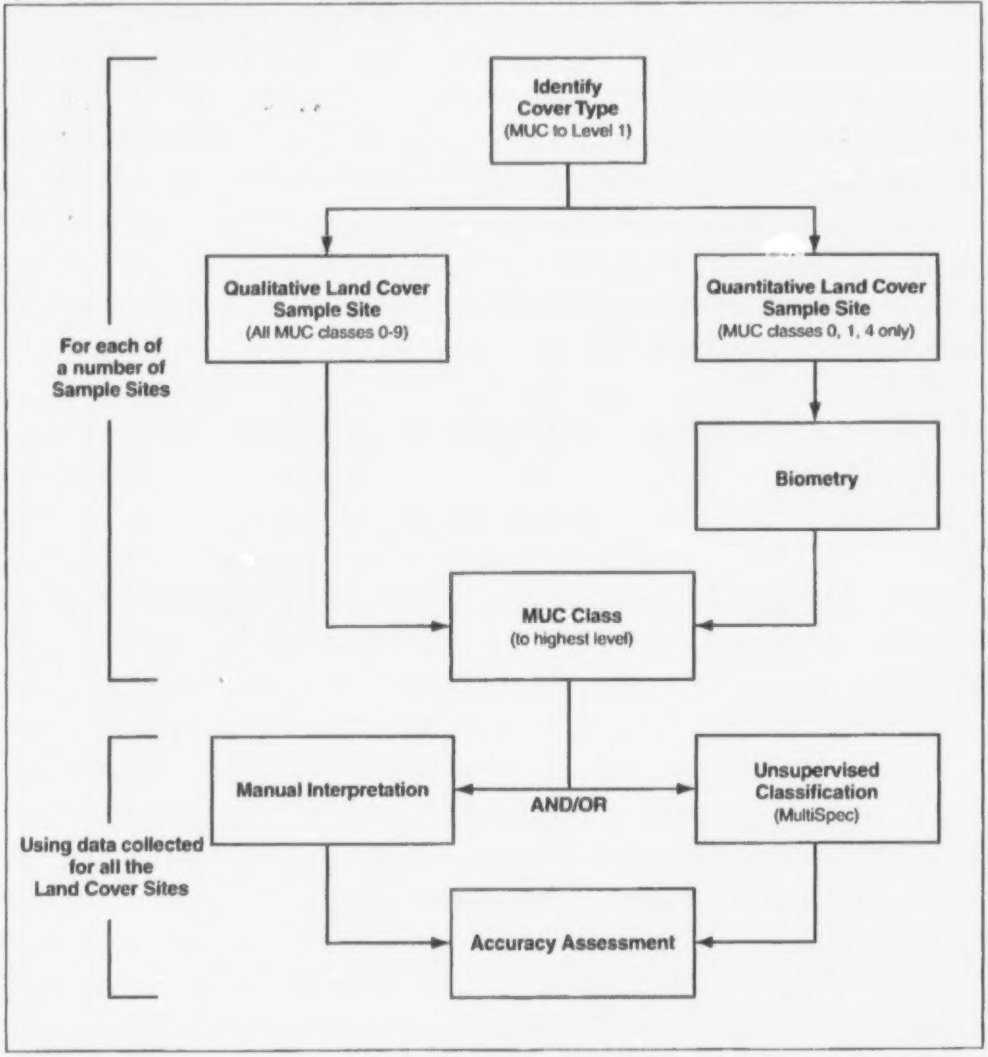
Quantitative Land Cover Sample Site. Only homogeneous areas of Forest, Woodland, or Herbaceous vegetation can be Quantitative Land Cover Sample Sites. You will learn more about this in the next section and in the *MUC System Protocol*.

The following flow diagram (Figure LAND-P-2) presents the steps to take to complete the Land Cover/Biology Investigation. The first step is to identify the general land cover type. All the other steps in this diagram correspond to protocols.

Identify the General Land Cover Type

The characterization of GLOBE Land Cover Sample Sites can only proceed within the context of a specific land cover classification system. The system used for GLOBE is the Modified UNESCO Classification system (MUC). This classification system is a tool for putting every possible land cover type on Earth into a unique land cover class. Each MUC class is a distinct type of land cover, with a name and an identification number, or MUC code.

Figure LAND-P-2: Flow Chart of Land Cover/Biology Investigation


For each of a number of Sample Sites
Identify Cover Type (MUC to Level 1)
Qualitative Land Cover Sample Site (All MUC classes 0-9)
Quantitative Land Cover Sample Site (MUC classes 0, 1, 4 only)
Biometry
MUC Class (to highest level)
Using data collected for all the Land Cover Sites
Manual Interpretation
AND/OR
Unsupervised Classification (MultiSpec)
Accuracy Assessment

About the MUC System

The GLOBE program uses MUC, an ecological classification system which follows international standards and ecological terminology for the identification of specific land cover classes. By using a standard international classification system, all the GLOBE data may be compiled into a single regional or global land cover data set. Thus ground data may be gathered and used to validate remotely sensed data following the same scientific protocols worldwide. This classification system enables GLOBE participants to accurately describe the land cover at any one point on Earth using the identical criteria as all other GLOBE participants.

There are two components of the MUC system. Part one is the outline of the classification system, containing the hierarchical list of labels for every class. Part two is the glossary, with rules and definitions. Before classifying any land cover type, it is crucial to *always* check the definition of the particular land cover class you believe is appropriate. Even if you think you know what a forest is, you should check the definition to confirm that your site is, in fact, a forest and not a woodland.

MUC has a hierarchical, or tree, structure, with ten level 1 classes. These classes are very general and easily identified. You must select one unique MUC class to identify a land cover type at each MUC level, beginning at level 1. Within each level 1 class there are two to six more detailed level 2 classes. Level 2 classes are still quite general and easily distinguished. Levels 3 and 4 are more specific communities or vegetative associations. The hierarchical structure of the MUC system simplifies the classification process. At each level your choices are restricted to only those classes which fall within the single class you have selected at the previous level. Thus while the whole MUC classification system has over 150 classes, at each step your choice is typically among only three to five land cover types.

In order to conduct the Land Cover/Biology Investigation, it is necessary first to identify the level 1 MUC class for each Land Cover Sample Site Each level 1 class is general and can be identified by visually estimating the percentage of the ground covered by the land cover present at the sample site. Table LAND-P-1 shows the 10 level 1 MUC classes. All MUC level 1 classes are determined by the percentage of the total sample area covered by the dominant land cover type.

Identifying MUC Level 1 Class

1. Select an area of homogeneous land cover as your Land Cover Sample Site.
2. Visually estimate the percent of the ground covered by the dominant land cover.
3. Review MUC level 1 class definitions to be sure students understand them.
4. Proceed with the steps of How to Classify Land Cover Sample Sites to MUC level 1 given in the *MUC System Protocol*.

Table LAND-P-1: Level 1 MUC Land Cover Classes

MUC Code	MUC Level 1 Classes	Coverage Required
0.	Forest	>40% Trees, 5 meters tall, crowns interlocking
1.	Woodland	>40% Trees, 5 meters tall, crowns not interlocking
2.	Shrubland	>40% Shrubs, 0.5 to 5 meters tall
3.	Dwarf Shrubland	>40% Shrubs, under 0.5 meters tall
4.	Herbaceous Vegetation	>60% herbaceous plants, grasses, and broadleafed plants (forbs)
5.	Barren	<40% vegetative cover
6.	Wetland	>40% vegetative cover, includes marshes, swamps, bogs
7.	Open Water	>60% open water
8.	Cultivated Land	>60% non-native cultivated species
9.	Urban	>40% urban land cover (buildings, paved surfaces)

Once you have established the level 1 MUC class of a Land Cover Sample Site, you are ready to proceed with one of the Land Cover Sample Site Protocols. If a Land Cover Sample Site is a forest or woodland or is covered by herbaceous vegetation (i.e. MUC level 1 land cover classes 0, 1, or 4), students may take the biometry measurements described in the Quantitative Land Cover Sample Site and *Biometry Protocols*. In other areas, GLOBE does not currently have protocols for biometry or other detailed quantitative assessments of the land cover. For these sites, students should take the measurements in the *Qualitative Land Cover Sample Site Protocol*. In some cases, you may decide to use a particular site as a qualitative sample site and not take biometry measurements even though the level 1 MUC class of the site would allow it to be quantitative sample site.

Establishing Different Types of Sites

In general, GLOBE schools only establish one of their Quantitative Land Cover Sample Sites as a permanent Biology Study Site, but establishing more sites is permissible. Over time, the goal is to establish one or more Land Cover Sample Sites in each of the major types of land cover identified within your 15 km x 15 km Globe Study Site. Start with the most common types of cover, and continue to add sample sites until you have located them in as many of the cover types as possible. When your school has the GPS instrument, measure and record the center point longitude, latitude, and elevation of all Land Cover Sample Sites you have identified up to that time.

Additional Land Cover Sample Sites are important for verifying the accuracy of land cover maps, which is a key scientific objective of GLOBE. It is recognized, however, that it will take time, perhaps several successive years, to accumulate a set of sample sites representative of each important type of cover within your Globe Study Site. You may want to assign a cover type to each of several classes, so that no two classes are working in the same type of cover and so as much data as possible are collected.

Qualitative and Quantitative Land Cover Sample Sites and Their Use in Land Cover Mapping

There are two types of land cover data collected in the GLOBE protocols — *qualitative* and *quantitative*. There are also two purposes for which you will use these land cover data: (1) help in labeling your land cover map (training), and (2) validating (or assessing the accuracy) of your classified land cover map (validation). Both are critical components to any mapping project using remotely sensed data and are analogous to the ways in which scientists and others will use your data.

Both training and validation data are collected for 90 m x 90 m sites, usually within your 15 km x 15 km GLOBE Study Site. These sites are called *Land Cover Sample Sites, and* must be within areas of homogeneous land cover. See Figure LAND-P-3. For this investigation, homogeneous land cover means that the entire site is representative of one of the specific land cover classes defined in the *MUC System Protocol*.

Figure LAND-P-3: Homogeneous Land Cover Site

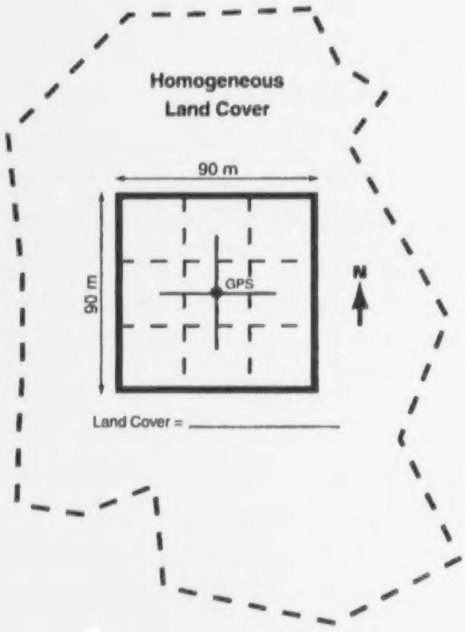


Table LAND-P-2: The Uses of Qualitative and Quantitative Data in Land Cover Mapping

		Data Type	
		Qualitative Land Cover Sample Sites	Quantitative Land Cover Sample Sites
Data Purpose	Training Data	Obtain the lay of the land during map development; assign land cover classes quickly	Gain a thorough understanding of the appearance of land cover types on ground and image
	Validation Data	More easily obtain enough land cover sites for statistically valid map accuracy assessment	Best for map accuracy assessment; detailed information about forest, woodland and herbaceous vegetation sites Helps students and scientists understand appearance of cover types on both the ground and satellite images

The following definitions should be helpful in understanding the difference between the types of data collected and the data collection methods.

Training Data: Land cover data collected at Land Cover Sample Sites to help identify or label unknown clusters on the unsupervised classification of the TM image and/or to help in the manual interpretation of the TM image. These data can be collected using qualitative or quantitative data collection methods. Training data should *never* be used to assess the accuracy of the map because they have been used in the training process and you can not use the same data to train as well as validate your results.

Validation Data: Land cover data collected at Land Cover Sample Sites to assess the accuracy of the classified map created using manual interpretation or unsupervised classification of your local TM scene. These data can be collected using qualitative or quantitative data collection methods (quantitative is preferred whenever possible). Collect as many samples as possible for each land cover type present on the map because many samples are needed in the accuracy assessment process. These data should be used *only* for accuracy assessment.

Qualitative Data: In GLOBE, qualitative observation of land cover at a Sample Site requires only 3 components: (1) determining the latitude, longitude, and elevation of the site using GPS, (2) defining the MUC class using student observations of the site, and (3) taking photos in the four *cardinal* directions (i.e. north, south, east and west). This abbreviated set of land cover data can be used for *either* training or validation sites. Qualitative data are useful, especially when initially learning what land cover classes exist in your area and how to correlate what the land cover types look like on the TM image with what the same areas look like on the ground.

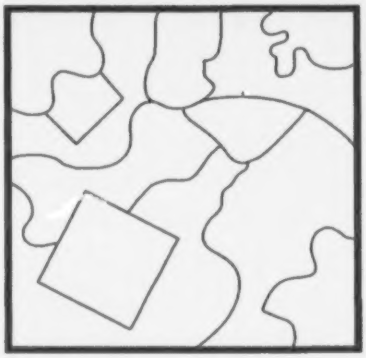
Quantitative Data: Quantitative land cover measurements are only possible for land cover classes for which GLOBE currently has Biometry Protocols (i.e., naturally occurring forest or woodland or herbaceous vegetation). In addition to the observations made for Qualitative Land Cover Sample Sites, at Quantitative Land Cover Sample Sites students take the measurements specified in the biometry protocol. These data are collected primarily for validation of maps generated from satellite imagery. The additional biometry measurements provide students and scientists with a more thorough understanding of forest, woodland, and herbaceous vegetation sites.

The Mapping and Accuracy Assessment Process

Figure LAND-L-4 illustrates the logical steps in producing a land cover map and assessing its accuracy. You are encouraged to begin collecting data on Land Cover Sample Sites even before you begin this mapping process. Student observations of individual sites are valuable because scientists can use them in their own land cover maps.

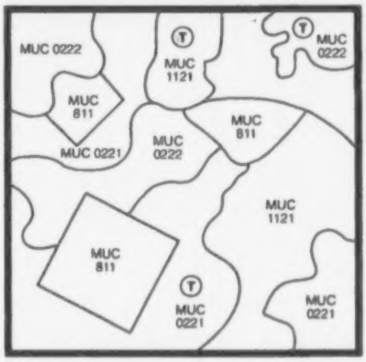
Figure LAND-P-4: Diagram of Accuracy Assessment Process

Step 1: Manual Interpretation or Unsupervised Clustering



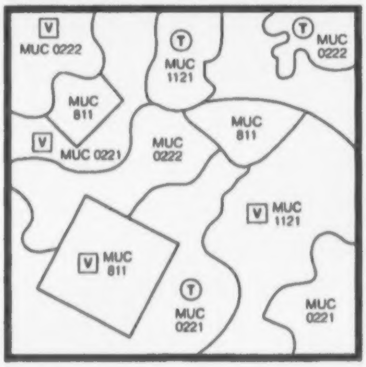
The TM image is divided into areas of similar land cover type manually or using MultiSpec.

Step 2: Assign MUC Classes to Areas or Clusters


MUC 0222
T
MUC 1121
T
MUC 0222
MUC 811
MUC 811
MUC 0221
MUC 0222
MUC 1121
MUC 811
T
MUC 0221
MUC 0221

For each area created by the manual interpretation or cluster created using MultiSpec, assign a MUC code using students' knowledge of the area and data collected from qualitative or quantitative training sample sites.

Step 3: Collect Validation Data


V
MUC 0222
T
MUC 1121
T
MUC 0222
MUC 811
V
MUC 0221
MUC 0222
MUC 811
V MUC 1121
V MUC 811
T
MUC 0221
MUC 0221

Once the land cover map is made, collect validation data at additional Land Cover Sample Sites to assess the accuracy of the classified map.

Over time, observe and measure as many validation sample sites as possible for each of the land cover types in your area.

Ⓣ **Training Sample**

V **Validation Sample**

Figure LAND-P-4: Diagram of Accuracy Assessment Process (continued)

Step 4: Assess Map Accuracy

		Validation Data				
		0222	0221	1121	811	**Row Total**
Map Classification	0222		1			1
	0221		1			1
	1121			1		1
	821				1	1
	Column Total	0	2	1	1	4

Using the difference/error matrix, compare the map classes to the validation sample classes determined from your observations and calculate the overall accuracy.

MUC Classes

0222 = Mainly deciduous forest with evergreen needle leaved trees

0221 = Mainly deciduous forest with evergreen broad leaved trees

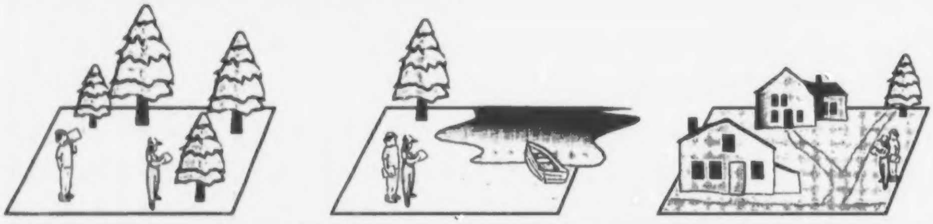
1121 = Mainly evergreen woodland with rounded crowns and needled leaves

811 = Pasture

Overall Accuracy = (3/4) * 100 = 75%

Figure LAND-P-5: Collect training and Validation Land Cover Samples

Collect Training and Validation Land Cover Samples



Special Considerations

Several time management, educational, and logistics issues should be considered in deciding how to present and undertake the various Land Cover/Biology protocols.

- Quantitative land cover information is far more useful and offers students a more complete view of the land cover assessment process.
- Measurement of a Quantitative Land Cover Sample Site involves careful biometry measurements, and students generally benefit from practicing these measurements before going to their study and sample sites.
- Virtually all GLOBE Study Sites contain developed areas of land cover, and in these areas only Qualitative Land Cover Sample Sites are possible.
- If a GPS receiver and a camera are available, observation of a Qualitative Land Cover Sample Site can be accomplished quickly.
- Data from multiple Land Cover Sample Sites are necessary in order to perform a manual interpretation of the entire GLOBE Study Site or to label the clusters that result from an unsupervised classification using MultiSpec. Even more validation sites must be collected to assess the accuracy of the land cover map generated either manually or using MultiSpec.
- Schools should collect as many sample sites as possible for each land cover type present on their land cover maps because many samples are needed in the accuracy assessment process; sites collected in different years and by different classes or even neighboring schools all can be used.
- The validation data must be independent of the data collected for training; it is not appropriate to use the same data for both training and validation because this will bias the results. Therefore, whatever data were collected and used for training must be set aside and only other samples used for validation.

Be sure to note the difference between naturally vegetated sites and cultivated sites. The Qualitative Land Cover Sample Sites can be collected for all land cover types. At present, the Quantitative Land Cover Sample Sites can only be collected for MUC classes 0, 1, and 4.

Qualitative Land Cover Sample Site Protocol

Purpose

To observe a Qualitative Land Cover Sample Site and collect the appropriate field data necessary for completing a land cover map from manual interpretation or unsupervised classification and for validating or assessing the accuracy of a land cover map

Overview

Qualitative field data are collected for a minimum of one Land Cover Sample Site for each land cover class in the GLOBE Study Site for which quantitative field data are not collected.

Time

20 - 45 minutes (excluding travel time)

Level

All

Frequency

Only need to collect data once for each Land Cover Sample Site

Multiple Land Cover Sample Sites are desired.

Key Concepts

Land cover map
Land cover classification
GPS
Field measurements

Skills

Locating a field plot (Land Cover Sample)
Using of GPS
Using field instrumentation (compass, tubular densiometer, clinometer)
Determining pace

Materials and Tools

Natural color, hard-copy TM image of your 15 km x 15 km GLOBE Study Site
Color infrared, hard-copy TM image of your 15 km x 15 km GLOBE Study Site
Compass
Tubular densiometer
Clinometer
GPS unit
Field form
Camera
MUC classification system and definitions

Preparation

None

Prerequisites

Leaf Classification Learning Activity

Introduction

The objective of collecting qualitative training and validation data is to familiarize the students with the entire GLOBE Study Site and identify the major land cover types present. These data can be collected rather quickly and efficiently, taking photos, using the GPS receiver to measure the location of the center of the site, and classifying the land cover using the MUC system. Qualitative training data can be used to label the unknown clusters resulting from unsupervised classification or as training areas for supervised classification. Data for additional Qualitative Land Cover Sample Sites can be used to determine the validity of your land cover map. It is anticipated that most schools will use this protocol many times to provide sufficient samples to perform a valid accuracy assessment of their land cover map. See the *Accuracy Assessment Protocol.*

How to Collect Qualitative Land Cover Sample Site Data

Step 1: Selecting and Locating Land Cover Sample Sites

☐ Select as your Land Cover Sample Site a 90 m x 90 m area of homogeneous land cover using either the TM image of your GLOBE Study Site or your observations in the field.

☐ Using the TM image for orientation, carefully locate and travel to the Land Cover Sample Site on the ground.

☐ Locate and carefully mark the center of the site with a temporary marker.

Step 2: GPS Location

☐ Obtain a Global Positioning System (GPS) unit. If you do not have the GPS unit when establishing a Land Cover Sample, make sure the center is clearly and durably marked and then come back and record the coordinates when you obtain a GPS unit.

☐ Perform the *GPS* or *Offset GPS Protocols* to determine the longitude, latitude, and elevation of the center of the Land Cover Sample Site. See the *GPS Investigation*.

☐ Record these data on the appropriate GPS Data Work Sheet and note the average latitude, longitude and elevation calculated on the Land Cover/Biology Investigation Field Data Work Sheet.

Step 3: Photos

☐ From the center of the site, take a photo in each of the four cardinal directions (N, S, E, W).

☐ Have two sets of prints developed or print out your digital photo.

☐ Label each photo with Land Cover Sample Site name and directional aspect.

☐ Retain one print or a copy of the digital photo for your school and send to GLOBE one print of each photo or a copy of the files for your digital photos.

Step 4: Determine MUC Class

☐ Perform the *MUC Protocol* to determine the MUC class. See helpful hints: *Pacing, Compass.*

☐ Record the MUC class on the Field Data Work Sheet.

Step 5: Report Data

☐ Review the data work sheets and record data in the school's permanent local data record.

☐ Report the data to GLOBE using the Qualitative Land Cover Sample Site Data Entry Sheet.

☐ Send copies of photos to the GLOBE Student Data Archive.

Helpful Hints: Pacing

Scientists, foresters, and others use pacing and compass bearings in conjunction with aerial photographs, maps or written instructions to find specific ground locations. As a convenience, many people who do field work determine how many of their paces it takes to travel a short set distance and use this to measure longer overall distances.

Pacing is specifically used in the MUC System and Qualitative and Quantitative Land Cover Sample Site Protocols to determine sampling points at which to take observations of ground cover and canopy cover. Methods for determining the length of one pace and the number of paces required to travel a set distance (called a *unit*) are discussed below.

Method for Determining the Length of One Pace

Step 1:
Lay out a 30 meter or longer measuring tape on a flat, open area (a parking lot, field, or hallway is good).

Step 2:
Remember that *one* pace is *two steps*. Starting with your toe at the 0 meter mark, pace off 10 paces, using a normal stride. It is important to use a normal, comfortable stride because of the wide variety of conditions encountered in the field.

Step 3:
Note the marking on the tape where your toe is on the tenth pace.

Step 4:
Divide that value by 10 to find the length of your pace.

Step 5:
Repeat this measurement three times and calculate the average to determine your average pace.

Example:

Repetition Number	Distance of 10 Paces	Distance of Single Pace
1	17.0 m	1.70 m
2	17.5 m	1.75 m
3	16.8 m	1.68 m
Average Pace = 1.71 meters per pace		

What To Do When in the Field

Pacing in the woods or over hilly terrain is quite different than pacing a flat distance in a school yard or parking area. Remember the following tips:

- When initially measuring your pace, be sure to walk using a comfortable stride. Resist the temptation to take exaggerated steps because your pace will naturally become shorter in the woods or over hilly terrain.
- When pacing up or down a hill, you are actually traveling a shorter horizontal distance than it seems, and you may also pace irregularly due to the terrain. Be aware of your paces and compensate by taking slightly shorter or longer steps as necessary.
- When large objects (boulders, large trees, etc.) are in the way, take a lateral side step, pace forward, then take another lateral side step back to your original compass bearing. If an observation is required while side-stepping and pacing around an obstacle, then estimate the reading from the side-stepped position.

If an object is too large to conveniently side step, leave a visible marker to find your place and walk all the way around. Start counting again at the marker on the other side of the object.

Method for Determining the Number of Paces Required to Travel One Unit

In the MUC, Qualitative, and Quantitative Protocols students are required to collect canopy and ground cover data for a distance of **1 unit = 21.2 meters** from the center of the Land Cover Sample Site. This distance was chosen because it is half the diagonal of a 30 m x 30 m pixel.

Step 1:
Measure a distance of 21.2 meters out on a flat, open area (a parking lot, field, or hallway is good).

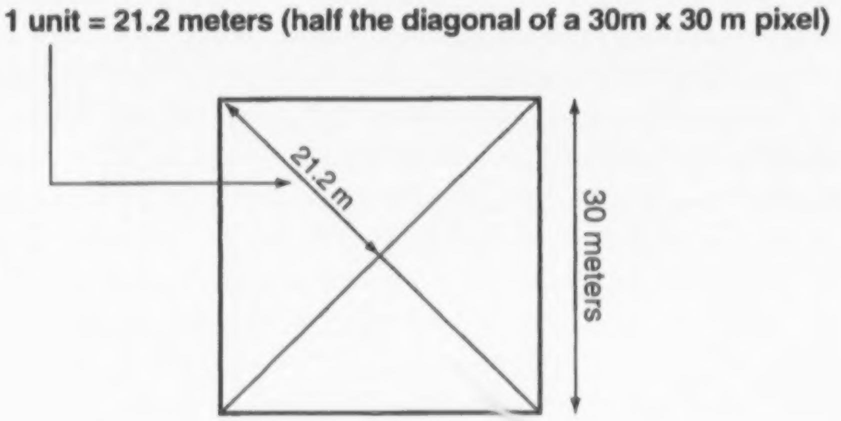
Step 2:
Remember that *one* pace is *two steps*. Starting with your toe at the 0 meter mark count the number of paces required to travel the entire distance using a normal stride.

Step 3:
Repeat this measurement three times and calculate the average to determine an average number of paces.

Step 4:
Round the number of paces to the nearest half pace.

Step 5:
Record each individual's pace so it can be referred to when collecting data at a land cover sample site.

Figure LAND-P-6: Pacing Example


1 unit = 21.2 meters (half the diagonal of a 30m x 30 m pixel)
21.2 m
30 meters

Helpful Hints: Compass

The magnetic needle in a compass is attracted by the magnetism of the Earth, and that is why it always points North. However, there are really two North Poles on the Earth. One is the *True North Pole* which is located geographically at the top of the earth (at 90° North latitude); and the other is the *Magnetic North Pole*, an area of highly magnetic rock under central Canada.

Maps and directions are based on True North while the compass needle points to Magnetic North. Magnetic declination is the angle between True North and Magnetic North. Its size and direction depends on where you are on the Earth. It is necessary to determine the declination to take accurate compass bearings. Compasses either have a mechanism to set the angle of declination or a scale to determine declination.

Because compasses are attracted to metal objects they will give incorrect readings if the user is close to, or wearing, metal objects including watches, keys, etc.

Three Basic Parts of the Compass

1. The *magnetic needle* (See A in the Figure LAND-P-7) is attracted by the magnetic North Pole of the earth. The magnetic end (black) always points to magnetic north
2. The *graduated dial* (B) is used to set the desired bearing. The bearing is read in degrees at the sighting arrow (C) at the top of the compass. The dial is graduated in 2 degree increments from 0 to 360 degrees. The cardinal directions are at 0 (or 360), 90 degrees, 180 degrees and 270 degrees which correspond to North, East, South and West.
3. The *base plate* (D) has an orienting arrow (E) and a sighting arrow (C). Some models also have mirror sights attached. These components are used to line up the magnetic needle and point out the "line of travel".

Setting Compass Bearings

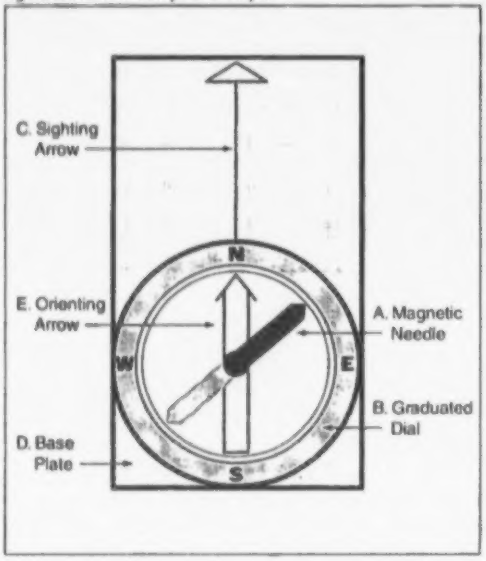
Step 1:
Set the dial (B) to the desired degree reading (the direction in which you want to travel) so that the correct compass bearing lines up with the sighting arrow (C).

Step 2:
While holding the compass level, turn your body until the red end of the magnetic needle (A) lines up with the red orienting arrow (E). "Put the red in the shed" is a useful saying to help students remember what to do. The red orienting arrow is considered the "shed."

Step 3:
Your direction or objective will now lie straight ahead in the direction you are holding the compass (the direction in which the sighting arrow points).

Be sure to choose an object ahead of you in line with your compass bearing and walk toward it. This allows you to walk without looking down at your compass. Every few paces stop and check that you are still traveling in the desired compass direction.

Figure LAND-P-7: Compass Example



Quantitative Land Cover Sample Site Protocol

Purpose

To measure Quantitative Land Cover Sample Sites and to collect the appropriate field data necessary for completing a land cover map made using either manual or unsupervised computer methods and for validating or assessing the accuracy of the land cover map

Overview

Quantitative field data is collected for a minimum of one Land Cover Sample.

Time

1-2 hours (excluding travel time)

Level

All

Frequency

Only collect data once for each Land Cover Sample Site.

Multiple Land Cover Sample Sites are desired. Over time, try to perform this protocol at least once for each major type of land cover within your GLOBE Study Site that is in MUC level 1 class 0, 1, or 4.

Key Concepts

Land cover map
Land cover classification
GPS
Field measurements
Biometry

Skills

Locating a field plot (Land Cover Sample)
Using of GPS
Using a compass, tubular densiometer, and clinometer
Determining pace

Materials and Tools

Natural color, hard-copy TM image of your 15 km x 15 km GLOBE Study Site
False-color infrared, hard-copy TM image of your 15 km x 15 km GLOBE Study Site
Compass
Tubular densiometer
Clinometer
Tape measure
GPS unit
Land Cover/Biology Field Data Work Sheet
Camera
MUC classification system and definitions

Preparation

None

Prerequisites

Leaf Classification Learning Activity

Introduction

Quantitative training and validation data provides the most detailed ground reference data possible. These data are used in quantitatively assessing the accuracy of remotely sensed maps. Every school is expected to collect data from at least one Quantitative Land Cover Sample Site, but each school is encouraged to collect as many Quantitative Land Cover Samples as they can. It is critical to scientists to have as much validation data as possible. It is also important to have validation data in every land cover class in the GLOBE study site. Obviously, this data collection should continue through time and can result in a large and very valuable database of validation sites.

Steps for Quantitative Data Collection

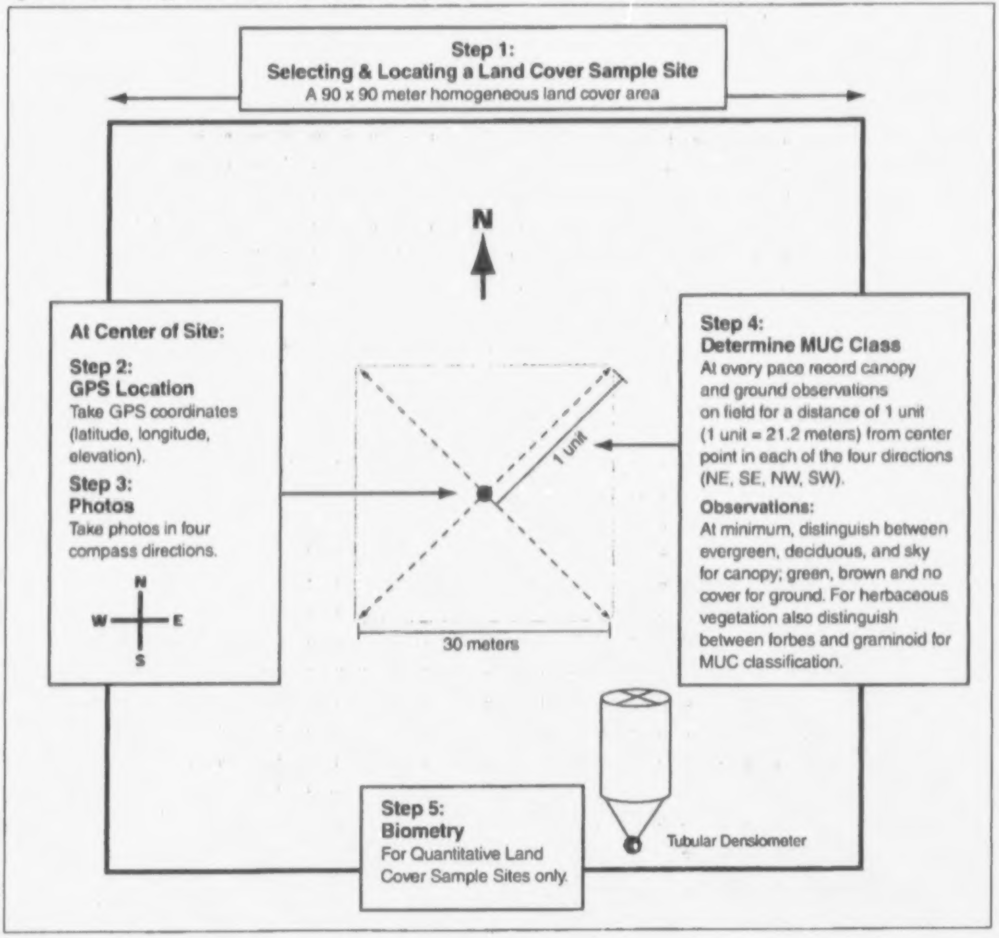
Step 1: Selecting and Locating a Quantitative Land Cover Sample Site

- ☐ Select a 90 m x 90 m area of homogeneous land cover using either the TM image of your GLOBE Study Site or your observations in the field.
- ☐ Using the TM image for orientation, locate and travel to the Land Cover Sample Site.
- ☐ Carefully mark the center of the site with a temporary marker.

Step 2: GPS Location

- ☐ Obtain a Global Positioning System (GPS) unit. If you do not have the GPS unit when establishing a Land Cover Sample, make sure the center is clearly marked and then come back and record coordinates when you obtain the GPS unit.
- ☐ At the center of the Land Cover Sample Site, record the GPS coordinates: longitude, latitude, and elevation. Refer to the *GPS Investigation*.
- ☐ Record on Land Cover/Biology Investigation Field Data Work Sheet.

Figure LAND-P-8: A Typical Quantitative Land Cover Sample Site



Step 1:
Selecting & Locating a Land Cover Sample Site
A 90 x 90 meter homogeneous land cover area

At Center of Site:

Step 2:
GPS Location
Take GPS coordinates (latitude, longitude, elevation).

Step 3:
Photos
Take photos in four compass directions.

Step 4:
Determine MUC Class
At every pace record canopy and ground observations on field for a distance of 1 unit (1 unit = 21.2 meters) from center point in each of the four directions (NE, SE, NW, SW).

Observations:
At minimum, distinguish between evergreen, deciduous, and sky for canopy; green, brown and no cover for ground. For herbaceous vegetation also distinguish between forbes and graminoid for MUC classification.

Step 5:
Biometry
For Quantitative Land Cover Sample Sites only.

Step 3: Photos

- ☐ From the center of the Land Cover Sample, take a photo in each of the four cardinal directions (N, E, S, W).
- ☐ Have two sets of prints made, one for your school and one for GLOBE.
- ☐ Label each photo with Land Cover Sample Site name and directional aspect.

Step 4: Determine MUC Class

- ☐ Determine the land cover class following the MUC System Protocol.
- ☐ Record the MUC Class on Land Cover/ Biology Investigation Field Data Work Sheet.

Step 5: Biometry

- ☐ If the site is a forest or woodland (i.e. MUC classes 0 or 1), follow forest biometry protocols (height, circumference, dominant and sub-dominant species identification, crown closure, ground cover).
- ☐ If the site is covered by herbaceous vegetation (MUC class 4), follow the grassland biometry protocols.

Step 6: Report Data

- ☐ Review the data work sheets and record data in the school's permanent local data record.
- ☐ Report the data to GLOBE using the Quantitative Land Cover Sample Site Data Entry Sheet.
- ☐ Send copies of photos to the GLOBE Student Data Archive.

Biometry Protocol

Purpose

To quantify and record the land cover in order to determine the specific characteristics of a Quantitative Land Cover Sample Site

To provide GLOBE scientists and others with necessary land cover data

Overview

Students lay out a 30 m x 30 m area within a Quantitative Land Cover Sample Site. At these sites, students observe and record ground cover and canopy cover, identify dominant and co-dominant vegetation species, measure either tree height and circumference or the biomass of the herbaceous ground cover. They designate one of these sites as their Biology Study Site, where they will perform this protocol once or twice each year.

Time

One-half to one full day for each visit

Level

All

Frequency

One to two times per year for your Biology Study Site

One time only for all other Quantitative Land Cover Sample Sites

Key Concepts

- Relation of the pixel size of an image to a site on the ground
- Canopy Cover
- Ground Cover
- Tree Height and Circumference
- *Biomass* of herbaceous vegetation
- Dominant and *Co-Dominant* Species
- Land Cover Classification

Skills

- *Using* a clinometer and densiometer.
- *Using* compass directions
- *Making* ground measurements
- *Identifying* vegetation types and tree species
- *Using* a dichotomous key
- *Measuring* pace

Materials and Tools

- Color printed copies of your local 512 x 512 pixel Landsat Thematic Mapper scene in visible (3, 2, 1) and NIR (4, 3, 2)
- Local road or topographic maps (optional)
- Compass
- 50 m Tape measure
- Marking stakes, flags, or other permanent site markers
- GPS Unit
- Still Camera
- Tubular densiometer (4 cm diameter by 7.5 cm long tube, string, metal nut or washer, tape)
- Dichotomous keys and/or other local species guides
- Clinometer (Clinometer Sheet, cardboard, drinking straw, metal nut or washer)
- Table of Tangents
- Flexible tape measure
- Small bean bag
- Grass clippers or strong scissors
- Small brown paper bags
- Drying oven
- Balance or scale, accurate to 0.1 g
- Land Cover/Biology Investigation Field Data Work Sheet

Preparation

Select site(s)

Practice measurement techniques

Prerequisites

Site Seeing Learning Activity

Introduction

The *Quantitative Land Cover Sample Site Protocol* shows you how to establish Quantitative Land Cover Sample Sites and outlines the steps for collecting data on them. This protocol details the procedures for performing *biometry* measurements at all quantitative sites. This protocol can only be performed on sites with MUC level 1 class 0 (Closed Forest), 1 (Woodland), or 4 (Herbaceous Vegetation). You establish one of these quantitative sites as your Biology Study Site.

How to Lay-out a 30 m by 30 m Area for Biometry Measurements

Special Considerations for Biology Study Sites

Note: If you have already followed an earlier version of this protocol and have established a Biology Study Site, continue to use your current site for repetitive measurement following the later sections of this protocol.

The only difference between your Biology Study Site and the central 30 m x 30 m areas of other Quantitative Land Cover Sample Sites is that biometry measurements are repeated periodically at the study site while at sample sites observations are made just once. After identifying the dominant and co-dominant vegetation types, you will perform a series of biometry measurements over time.

Since your Biology Study Site is permanent, you need to mark the 30 m x 30 m center area where you perform all your measurements with permanent stakes, flags, or other markers. To mark this 30 m x 30 m area:

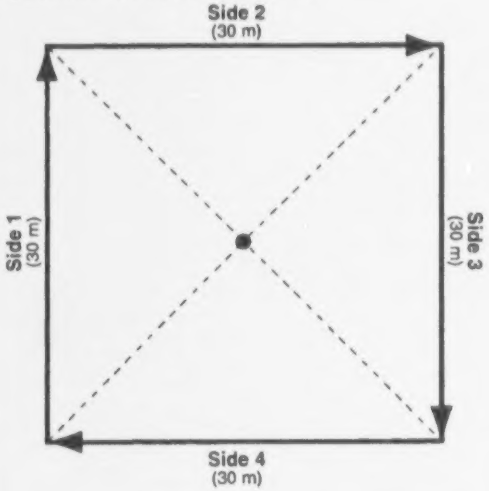
Step 1: Establish Your Biology Study Site

- ☐ Follow Steps 1 through 4 of the Quantitative Land Cover Sample Site Protocol. Make sure this site is a MUC level 1 class 0, 1, or 4 area.

Step 2: Establish and Mark Your 30 m x 30 m Biology Study Area

- ☐ Place a marker where you want one corner of your 30 m x 30 m square to be.
- ☐ Use your compass and measuring tape to move 30 meters in a *cardinal* direction (North, South, East, or West). Place a second marker at the end of this transect. This forms side one.
- ☐ From the second marker, move 30 meters perpendicular to side one. Place a third marker at the end of this transect. This forms side two.
- ☐ From the third marker, move 30 meters perpendicular to side two and parallel to side one. Place a fourth marker at the end of this transect. This forms side three.
- ☐ From the fourth marker, move 30 meters toward your original marker. If this transect ends within 2 to 3 meters of the original marker, you are successful. If you are farther off the mark, check your compass headings for each side, check the length of each side, and try again.
- ☐ Establish the center of your square by pacing the diagonal transects of the square and placing a marker where the two paths intersect. You may use string to make these diagonals.

Figure LAND-P-9: Biology Study Site Set-up



Making Biometry Measurements

Depending on the types of vegetation at your site, you and your students will make biometry measurements on canopy cover, ground cover, tree height and circumference, and/or grass biomass.

When to Make Biometry Measurements

At your Biology Study Site: make biometry measurements twice each year—once during peak growing season and once during the least active season. If you have no temperature or rainfall-dependent seasonality in your region, take measurements only once a year.

At all other Quantitative Land Cover Sample Sites: perform biometry measurements just once, as close to the peak of the growing season as possible.

How to Make Canopy Cover and Ground Cover Measurements

Step 1: Make a Densiometer

☐ Take a tube approximately 4 cm in diameter and 7.5 cm long. Attach two strings at perpendicular angles across the diameter of one end to form a crosshair.

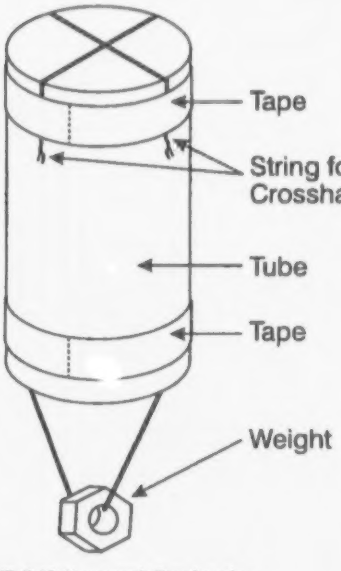


Figure LAND-P-10: Homemade Densiometer

☐ Attach an 18 cm piece of string with a metal nut or washer hanging loosely from it across the diameter of the other end of the tube. You have made a densiometer.

Step 2: Tally Canopy Cover and Ground Cover

☐ One or more pairs of students pace the two diagonals of the 30 m x 30 m square.

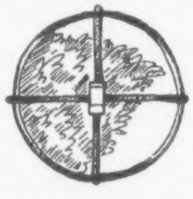
☐ After every pace, one student looks up at the canopy through the densiometer, making sure the metal nut/washer is directly below the intersection of the crosshairs at the top of the tube.
Note: If it takes smaller students more than forty paces to complete a diagonal, they may take measurements at every other pace.

☐ If the student sees vegetation, twigs, or branches touching the crosshair intersection, the other student records a " + " in the proper space on the Dominant/Co-Dominant Vegetation Field Data Work Sheet. If no vegetation, twigs, or branches touch the crosshair intersection (i.e. the student sees the sky above the intersection of the crosshairs), the student records a " - ". The students should end up with a series of +'s and -'s.

☐ Now, the student looks down.

☐ If vegetation is underfoot or touches the foot or leg below the knee, the other student records a "G" if the vegetation is green, a "B" if the vegetation is brown, or if no vegetation touches the student underfoot or below the knee (i.e. the ground is bare), the other student records a " – ".

For more accurate readings, other pairs of students should repeat these measurements.



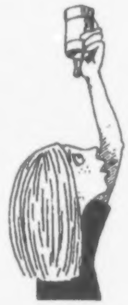
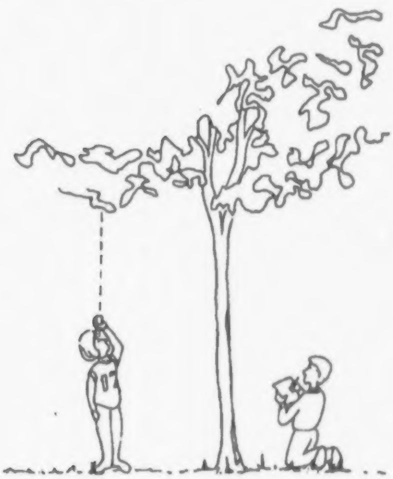


Figure LAND-P-11: Example using a homemade densiometer



Step 3: Report Findings for Canopy Cover and Ground Cover

- ☐ Report the number of +'s and -'s for canopy cover and the number of G's, B's, and -'s for ground cover to the GLOBE Student Data Server along with other biometry data.

  Note: If observations were repeated by different teams of students, choose only one team's set of data to report to GLOBE.

Step 4: Calculate Percentages of Canopy Cover and Ground Cover

- ☐ Calculate canopy cover percentage: Add up all +'s and divide by the sum of the +'s plus -'s. Multiply by 100 to convert this fraction to a percentage.
- ☐ Calculate green ground cover percentage: add up the G's and divide by the sum of the G's, B's, and -'s. Multiply by 100 to convert this fraction to a percentage.
- ☐ Calculate brown ground cover percentage: add up the B's and divide by the sum of the G's, B's, and -'s. Multiply by 100.
- ☐ Add the green ground cover and brown ground cover percentages together to obtain a total ground cover percentage.

How To Identify Dominant and Co-Dominant Vegetation

Having established your site(s), you have a general idea of what types of vegetation grow there. You and your students will now identify the most common (dominant) and second most common (co-dominant) vegetation types on your Biology Study Site or other Quantitative Land Cover Sample Sites. You may need this information to help you identify the MUC classification of your site using the *MUC Classification Protocol*. GLOBE scientists also need this information to study the growth of different kinds of vegetation. For Closed Forest and Woodland sites (MUC level 1 classes 0 and 1) we ask you to identify the scientific names (genus and species) of the two types of trees that have the most canopy coverage. For herbaceous sites (MUC level 1 class 4), identify the plant(s) that cover the most ground as *graminoid* (grass), or *forb* (broad-leaved). Please see the MUC Glossary in the *Appendix* for definitions of these terms.

Step 1: Identify Vegetation Types

- ☐ Repeat the canopy cover and ground cover measurements given above but this time the student identifies each tree species that touches the crosshair. The student also looks at the ground and identifies any vegetation type underfoot or touching her foot or leg. The other student records the types on the Dominant/Co-Dominant Vegetation Field Data Work Sheet.

Note: If you cannot identify the genus and species of a tree in the field, record the common tree name, if known. If the common name is not known, invent names and describe the tree well so that you can accurately identify it later.

Step 2: Calculate Which Vegetation Types Are Dominant and Which Are Co-Dominant

- ☐ Tabulate your results.
- ☐ If tree canopy cover is 40% or greater and the canopy is above 5 m in height, then your site is Forest or Woodland (MUC level 1 classes 0 or 1). The *dominant* vegetation is the tree species seen the most times through the densiometer. The *co-dominant* vegetation is the tree species

seen the second-most times. If your site is forest or woodland, identify the tree species using dichotomous keys or by consulting local experts. See Helpful Hint: How to Use Dichotomous Keys. Then, proceed to How to Measure Tree Height and Circumference.

- ☐ If tree canopy cover is less than 40%, and your ground cover is more than 60%, then your site is dominated by Herbaceous Vegetation (MUC level 1, class 4). The *dominant* vegetation is the plant seen the most times as part of the ground cover. The *co-dominant* vegetation is the plant seen the second-most times either on the ground or in the canopy. If your site is herbaceous vegetation, identify whether the land covers are *graminoid*.(grasses) or *forb* (broad-leafed) using the definitions in the *Appendix*. If the herbaceous land cover is graminoid, proceed to How to Measure Grass Biomass. If the vegetation is broad-leaved, do not perform any further measurements or observations.

Step 3: Record Your Findings

- ☐ If your site is Forest or Woodland, enter the first four letters of the genus and species for both the dominant and co-dominant tree species in the proper space on your Dominant/Co-Dominant Vegetation Field Data Work Sheet.
- ☐ If your site is Herbaceous Vegetation, enter either "GRAM," for grass (graminoid), or "FORB" for other, broad-leaved vegetation, in the proper space on your Data Work Sheet.

Note: If the vegetation on your site is diverse, it may be difficult to identify the dominant and co-dominant vegetation. If two types are not clearly dominant and co-dominant, describe the vegetation types well in the Notes section of your Dominant/Co-Dominant Vegetation Field Data Work Sheet. Enter "mixed" on the *Dominant/Co-Dominant* line.

Examples

To give you a better sense of how this activity works, here are two examples of what might happen:

Example 1: You perform your canopy cover and ground cover measurements, recording the number of times you saw vegetation through your densiometer and the number of times you saw sky. Each time you see canopy vegetation through your densiometer, you also record and tally the tree species. You then calculate a canopy cover of 70% and note that the crowns of trees are touching each other. This means you classify your site as a *forest* (MUC level 1 class 0). The dominant tree species is the species with the most tallies. The co-dominant species is the species with the second most tallies.

Example 2: After you perform your canopy and ground cover measurements, you calculate that the canopy cover is 20% and composed of a single species of pine tree. Your ground cover is 90%, and is composed of 80% grass and 10% forb. This means you classify your site as *herbaceous vegetation* (MUC level 1 class 4). The dominant vegetation is grass ("GRAM" on the Data Work Sheet). Since 20% of the site is pine tree and only 10% of the site is forb, your co-dominant vegetation is the pine tree species.

Helpful Hints: How to Use Dichotomous Keys

The word *dichotomous* comes from the Greek words *dikha*, "in two," and *temnein*, "to cut." Thus, it's meaning: "division into two contradictory parts." A *key* is a table glossary, or cipher, for decoding or interpreting. A *dichotomous key* is a branching decoder, which forks into two approximately equal and contradictory divisions that lead to only one correct outcome. It is like a mouse maze. For the mouse to escape, it must make successive choices between two directions, one correct and one incorrect. The mouse will get out only after making all the correct choices.

To use a dichotomous key we, too, must choose correctly between two options in a series of contradictory options. We use our five senses (sight, hearing, touch, taste, and smell) to determine the correct choices. Here is a simple example of how we might choose what type of shoe we are wearing.

Assume you are wearing a pair of canvas running shoes. The first choice in the key asks if the shoes are made of leather or canvas. Since they are made of canvas, not leather, you follow the "path" to "CANVAS." Here you are asked if your shoes have lightweight soles and are low-cut or if they have heavy soles and are high-cut. Yours are lightweight and low-cut, so you have identified them as canvas running shoes.

Note that *all* dichotomous keys have inherent limitations. In this example, only six types of shoes are included. Even very extensive and technical keys omit some possible choices. This is especially true of exotic vegetation species that have been introduced into an area. Many dichotomous keys only include native species. If the plants you are trying to identify aren't native or your dichotomous key isn't complete enough, you may need to seek expert help.

A second limitation of many dichotomous keys is their use of imprecise terminology (e.g. "low-cut," "lightweight," etc.). Sometimes it is not clear what the authors of the key mean by these terms. The best keys are those that use objective, measurement-based characteristics rather than subjective options.

To help you identify species or find a local dichotomous key, consult foresters, local experts, university research scientists, etc. Your GLOBE Country Coordinator may also have useful information.

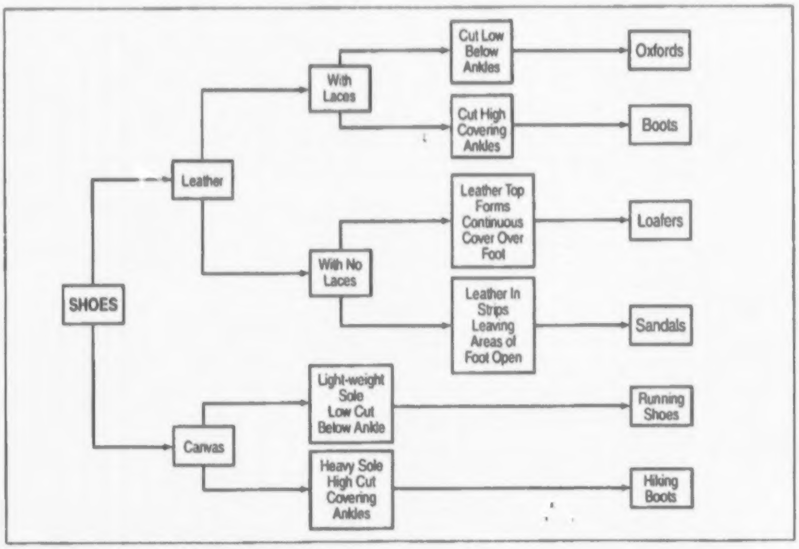

Cut Low Below Ankles
Oxfords
With Laces
Cut High Covering Ankles
Boots
Leather
Leather Top Forms Continuous Cover Over Foot
Loafers
With No Laces
SHOES
Leather In Strips Leaving Areas of Foot Open
Sandals
Light-weight Sole Low Cut Below Ankle
Running Shoes
Canvas
Heavy Sole High Cut Covering Ankles
Hiking Boots

Figure LAND-P-12: Using a Dichotomous Key

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How to Measure Tree Height and Circumference

How to Choose Which Trees to Measure

1. If the dominant species on your site is a tree, select five specimens of the tree. Include the largest tree, the smallest tree that still reaches the canopy, and three intermediate trees. Mark the trees for future reference.
2. If you have a co-dominant tree species, repeat the process. If there are fewer than five co-dominant species trees, include other tree species to make a total of five. Mark the trees for future reference.

How To Measure Tree Height Using a Clinometer

A clinometer measures angles to determine the heights of objects without directly measuring them. It is a simplified version of the *quadrant* (a medieval measuring instrument), and the *sextant*, an instrument used to locate the positions of ships. Like these instruments, the clinometer has an arc with graduated degree markings that go from 0 to 90 degrees. See Figure LAND-P-13. When you site an object through the clinometer's drinking straw, you can read the number of degrees of angle BVW by noting where the string touches the arc. Angle BVW is equal to angle BAC, which is the angle of elevation of the clinometer. If you know both the angle of elevation and your distance away from an object, you can calculate the height of that object using a simple equation.

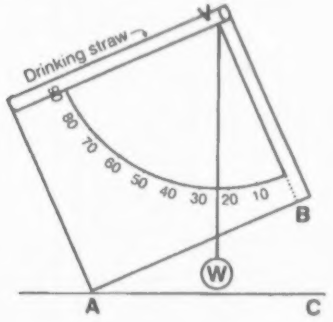


Figure LAND-P-13: Homemade Clinometer

Modified from Bennett, A. and Nelson, L. (1961) Mathematics an Activity Approach. Allyn & Bacon: Boston.

Step 1: Make a Clinometer

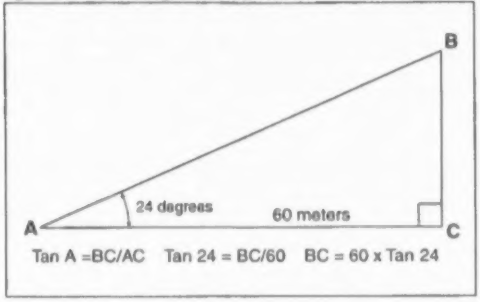
- ☐ Glue a copy of the Clinometer Sheet in the Appendix onto a same-size piece of stiff cardboard.
- ☐ Punch a hole through the marked circle on the sheet and tie one end of a 15 cm piece of string through it.
- ☐ Tie a metal nut or washer to the other end of the string.
- ☐ Tape a drinking straw along the designated line on the sheet, to use as a site.

Step 2: Measure and Record the Distances and Angles Needed to Determine Tree Height

- ☐ At one of your selected trees, move a predetermined distance away from the base of the tree and record the distance. This is your line AC. See Figure LAND-P-14. For the most accurate results you should adjust your distance away from the base of the tree so that Angle BVW is between 30 degrees and 60 degrees.
- ☐ Measure and record the height of your eye above the ground.
- ☐ Site the top of the tree through the drinking straw on the clinometer.
- ☐ Record the number of degrees in angle BVW on the clinometer; this tells you the number of degrees in angle BAC.

In the example (Figure LAND-P-15), a student stands 60m away from the base of a tree sites the top of the tree through his clinometer. His eye is 1.5 meters above ground. He reads an angle of 24 degrees on his clinometer (figures are not drawn to scale).

Figure LAND-P-14: Trigometric Equation



Step 3: Organize Your Data in a Drawing

Refer to Figure LAND-P-14 to draw and label a triangle that represents all the information you have accumulated.

Step 4: Calculate Tree Height

- ☐ Use your Table of Tangents in the Appendix and the following equation to solve for the height of BC:

TAN<A = BC/AC

The above student solved his equation like this:

TAN 24 = BC/60. Therefore,

BC = 60 (TAN 24). Therefore,

BC = 60(.45) = **27m**.

- ☐ Add the height of BC to the height of the clinometer from the ground (your eye level) to get the total height of the tree. In the above example, the height of the tree is 27m + 1.5m = **28.5m.**

Note: For younger students, if the angle BVW is 45 degrees, the distance from the tree will equal the height of the tree above the student's eye level and this can be illustrated for students by drawing an isosceles right triangle without any additional explanation of the mathematics involved.

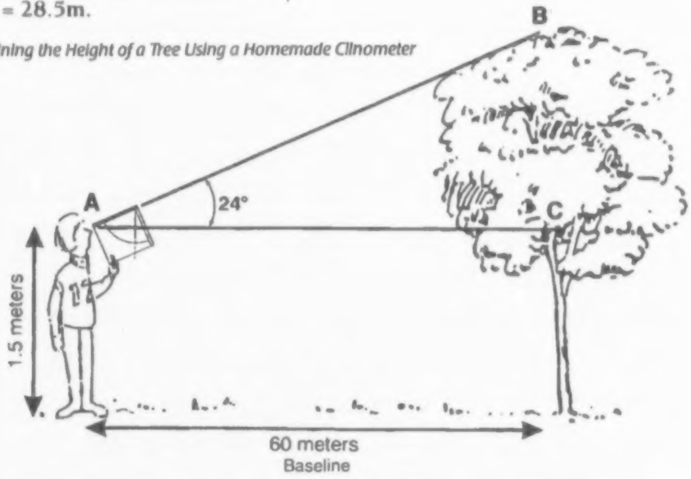
Step 5: Repeat the Above Process for All Selected Trees

Step 6: Calculate and Record Average Tree Height(s)

- ☐ Add the heights (in meters) of the dominant species trees and divide by five to obtain their average height.
- ☐ If you have five co-dominant species trees, repeat the process for them.
- ☐ Record tree height averages on your Data Work Sheet.

Note: If you would like to practice measuring heights before going to your site, find a tall outdoor object for which you know or can directly measure the height (such as a flagpole or the school building). After completing the above process, compare your results with the known height of the object.

Figure LAND-P-15: Determining the Height of a Tree Using a Homemade Clinometer



How To Measure Tree Circumference

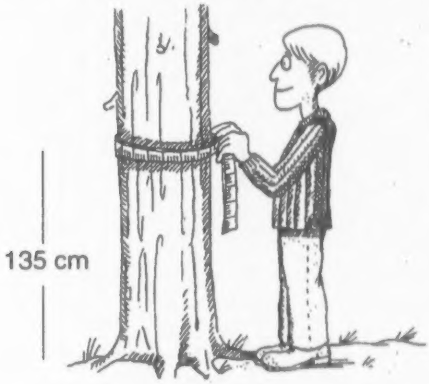
Step 1: Measure and Record Tree Circumference

☐ With a flexible tape measure, measure the tree's circumference at exactly 1.35 m above ground level. Scientists call this measurement *circumference at breast height* (*CBH*).

☐ Repeat process for all five dominant species trees and, when applicable, all five co-dominant species trees.

☐ Record circumferences in centimeters on your Land Cover/Biology Investigation Field Data Work Sheet.

Figure LAND-P-16: Measuring Tree Circumference



Source: Jan Smolik, 1996, TEREZA, Association for Environmental Education, Czech Republic

How To Measure Grass Biomass

If the dominant and/or co-dominant species at your site is grass, you will measure the *biomass* - the total mass of both live (green) and *senescent* (brown) herbaceous vegetation - per square meter on your site. This data will help others to document land cover and to assess and model water and nutrient cycles. Do not measure the biomass of any vegetation other than grasses, even if they are the dominant or co-dominant species present.

Step 1: Select and Mark Three Random Sampling Locations

☐ Blindfold a student and have him or her throw a small bean bag while you spin him or her at the center of your site. The bean bag's landing point will be one random sampling location.

☐ Repeat process twice more.

☐ At each sampling location, use a tape measure to mark out a one meter square on the ground.

Step 2: Collect and Sort Grass Clipping Samples

☐ Use garden clippers to clip all the grass vegetation within the square. When completed, the square should be devoid of any grass vegetation except for short stubs (*Vegetation* means it is still rooted in the ground. Do not collect any unattached leaves or litter).

☐ Sort clippings into living and senescent portions. Any clipping with even a little green is considered living. Only entirely brown clippings are senescent.

☐ Place the living and senescent portions into separate brown paper (*not* plastic) bags, and label each bag carefully. If your site has very extensive growth, use several small bags instead of two large ones.

Step 3: Prepare and Weigh Grass Clipping Samples

- ☐ Back at school, dry the bags over a period of days in a drying oven at a temperature no higher than 50 to 70 degrees celsius. Weigh each bag once a day. The samples are completely dry when you get the same mass on two consecutive days. (**Note:** Do *not* use a conventional cooking oven for this process; that would dangerous!)
- ☐ Weigh each bag, one at a time. Then, shake out the contents and weigh the empty bag. Subtract the empty bag weight from the total weight to get the weight of the grass. (Use a scale capable of measuring weights to plus or minus 0.1 g.)

Step 4: Record and Report Findings

- ☐ Record the weight in grams of both the green and brown material from each sample location.
- ☐ Report the weights of green and brown material for each of the three samples to the GLOBE Student Data Server.
- ☐ Calculate the average weight (biomass) of green material by adding the weights of the three samples and dividing by three. Record this weight in the Biometry Summary section of the Land Cover/Biology Investigation Field Data Work Sheet for future reference and comparison.
- ☐ Calculate the average weight (biomass) of brown material by adding the weights of the three samples and dividing by three. Record this weight in the Biometry Summary section of the Land Cover/Biology Investigation Field Data Work Sheet for future reference and comparison.

How to Enter Your Observations on the Land Cover/Biology Investigation Field Data Work Sheet

You will find a Land Cover/Biology Investigation Field Data Work Sheet in the *Appendix*, which you can use to record site observations and measurements. Make as many blank copies of this work sheet as you need. Use a separate work sheet each time your students make observations. This work sheet contains spaces to record every possible ground observation and measurement in this protocol. Depending upon what observations or measurements you make, some spaces will be left blank.

Your students should record the following data and information on the Land Cover/Biology Investigation Field Data Work Sheet:

1. **Site Identification:** Identify your Land Cover Sample Site. Designate the visit as either "training" or "validation" and as either "qualitative" or "quantitative." If it is a quantitative site, record whether it is your Biology Study Site.
2. **Site Name:** Identify the name you and your students give to your study site.
3. **Country/State/City:** Identify your locality using these identifiers.
4. **GPS Location:** Record the latitude and longitude of your site's center point, which has been determined using GPS.
5. **Date and Time:** Record the date and time of your field observations and measurements.
6. **Recorded By:** Record the name of the student or other person entering data on the form.
7. **MUC Land Cover Classes 2, 3, and 4:** Record the name and numerical code of the best match to your site's cover type as determined by the Modified UNESCO Classification System (MUC). If your cover is *urban* or *agricultural*, you may stop. All other observations and measurements are for natural vegetation.

8. **Dominant and Co-Dominant Species:**
   - If your dominant and/or co-dominant species are trees, enter the first four letters of the genus and species of each (as labeled in a dichotomous key).
   - If your dominant and/or co-dominant species are herbaceous vegetation, enter either "GRAM," for grass (graminoid), or "FORB" for other, broad-leaved vegetation.
   - If the vegetation on your site is diverse and the dominant and co-dominant species are impossible to ascertain, describe the vegetation types well in the Notes, Photographs section (below) and enter "mixed" on these lines.
9. **Canopy Cover:** Record + and - observations when using the densiometer method.
10. **Ground Cover:** Record the G, B, and - observations for ground cover.
11. **Number, Height, and Circumference of Trees:** Record the number of trees and the height and circumference measurements on your five dominant and five (when applicable) co-dominant tree species specimens. (If grasses are the dominant and co-dominant vegetation, leave these fields blank.)
12. **Green/Brown Biomass:** If your sample is dominated by grasses, record the green and brown biomasses for each of your sample locations after drying your samples at school. (If grass is not the dominant vegetation, leave these fields blank.)
13. **Biometry Summary:** Record the calculated canopy cover percentages, the green and brown ground cover percentages, the average tree height and circumference, and the average grass biomass obtained from combining the multiple samples.

    Note: Report all items marked by a star on the data form to the GLOBE Student Data Server.
14. **Notes, Photographs:** Record relevant field observations such as weather conditions, the number and orientation of photographs taken, etc.

MUC System Protocol

Purpose

To classify land cover using the Modified UNESCO Classification (MUC) System

Overview

Students will learn how to use this hierarchical classification system to assign a MUC class to their land cover sample sites.

Time

15 to 45 minutes to make field observations and determine proper MUC class (excluding travel time to and from the site)

Level

All

Frequency

For land cover samples sites: Determine MUC class once during peak foliage

Key Concepts

Canopy cover
Ground cover
Hierarchical land cover classification system

Skills

Using a compass
Measuring distances with paces
Using classification systems
Deciding based on definitions and rules
Identifying tree and ground cover types
Using the MUC system to identify the land cover class of a land cover sample site

Materials and Tools

MUC system and definitions
Compass
Tubular densiometer
Biometry Data Work Sheet

Preparation

Review the MUC system and the classification examples.

Identify MUC classes that are applicable to your local area.

Prerequisites

Leaf Classification Learning Activity

Learn to pace.

Learn to use the compass and densiometer.

Introduction

In GLOBE, we use the Modified UNESCO Classification (MUC) System for classifying land cover. MUC has an ecological basis and follows international standards. The MUC system has four levels of classification arranged hierarchically. As you can see in Tables LAND-P-3 and LAND-P-4 each higher level is based on more detailed properties of land cover. MUC codes of up to four digits are associated with each MUC class with one digit for each level in the class beginning with the lowest level. In assigning a MUC class to a homogeneous area of land cover, always begin at the lowest level (i.e. the first digit of the MUC code) and proceed up the levels one-by-one. The definitions of the MUC classes are given in the *Appendix*, and students should always refer to these definitions rather than trusting their memories or general knowledge when determining the MUC class for an area.

A classification system is a comprehensive set of categories, with labels and definitions, typically arranged in a hierarchy or branching structure. A classification system is used to organize a set of data, such as an inventory of land cover types, into meaningful groups. The classification system must be both *totally exhaustive* and *mutually exclusive*. A *totally exhaustive* classification has an appropriate class for every possible data point (e.g., land cover type). A *mutually exclusive*

Table LAND-P-3: MUC Level 1 and 2

	Level 1	Level 2
Natural Cover	0 Closed Forest	01 Mainly Evergreen Forest
		02 Mainly Deciduous Forest
		03 Extremely Xeromorphic (Dry) Forest
	1 Woodland	11 Mainly Evergreen Woodland
		12 Mainly Deciduous Woodland
		13 Extremely Xeromorphic (Dry) Woodland
	2 Shrubland	21 Mainly Evergreen Shrubland
		22 Mainly Deciduous Shrubland
		23 Extremely Xeromorphic (Dry) Shrubland
	3 Dwarf-shrubland	31 Mainly Evergreen Dwarf-shrubland
		32 Mainly Deciduous Dwarf-shrubland
		33 Extremely Xeromorphic Dwarf-shrubland
		34 Tundra
	4 Herbaceous Vegetation	41 Tall Graminoid
		42 Medium Tall
		43 Short Graminoid
		44 Forb (broad-leaved) Vegetation
	5 Barren Land	51 Dry Salt Flats
		52 Sandy Areas
		53 Bare Rock
		54 Perennial Snowfields
		55 Glaciers
		56 Other
	6 Wetland	61 Riverine
		62 Palustrine
		63 Estaurine
		64 Lacustrine
	7 Open Water	71 Freshwater
		72 Marine
Developed Cover	8 Cultivated Land	81 Agriculture
		82 Non-agriculture
	9 Urban	91 Residential
		92 Commercial/Industrial
		93 Transportation
		94 Other

Sources: UNESCO, 1973 and GLOBE, 1996

classification has one and only one appropriate class for every data point. The hierarchical arrangement means that there are multiple levels of classes: level 1 has the most general classes; each higher level in the system increases in detail and multiple detailed classes may be condensed into fewer more general classes. For example:

The MUC System has ten level 1 classes, including *Closed Forest*, *Woodland*, and *Urban*. See Tables LAND-P-3 and LAND-P-4. The level 2 classes within *Closed Forest* are *Mainly Evergreen Forest*, *Mainly Deciduous Forest*, and *Extremely Xeromorphic (dry) Forest*. These level 2 classes contain more detail than the level 1 class, *Closed Forest*, and they may all be collapsed into the *Closed Forest* class. In other words, any member of one of these three Level 2 classes is always a member of the *Closed Forest* level 1 class. Table LAND-P-3 is a condensed version of MUC, showing only the level 1 and level 2 classes.

The entire MUC classification system is outlined in Table LAND-P-4. Be aware that this outline contains only the name and identifying code number of each class. The full definition and description of each class is detailed in the Glossary of Terms for the Modified UNESCO Classification System. The Glossary is found in the *Appendix*. Each class is strictly defined by clear decision criteria.

An Example of Determining MUC Class to Level 2

Figure LAND-P-17 illustrates the criteria used to distinguish between Forest and Woodland classes at MUC level 1 criteria used to distinguish between Mainly Deciduous, Mainly Evergreen, and Mainly Xeromorphic cover types at level 2.

More than 40% of the land cover sample must be covered by trees to qualify as forest or woodland. If the tree crowns are interlocking (branches from neighboring trees touch each other) the sample site is considered forest. If the trees are spread farther apart and branches do not touch each other, the sample site is considered woodland. The level 2 classes typically depend on the composition of the level 1 cover type. In this example, the level 2 class for Forest or Woodland depends upon the percentage of deciduous and evergreen trees in the canopy.

Figure LAND-P-17: Applying MUC to Forest and Woodland

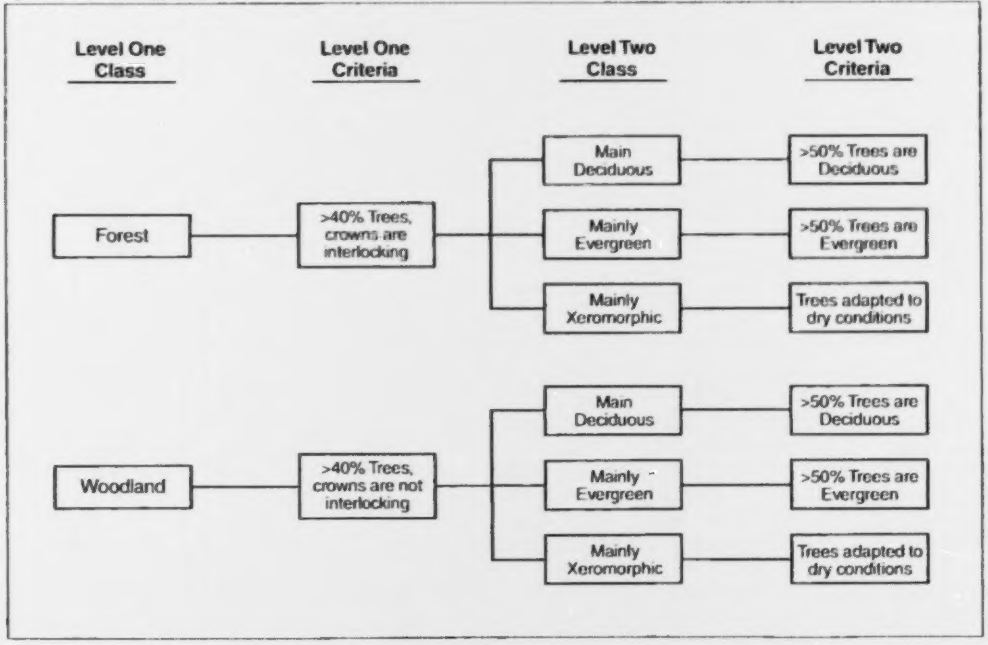

Level One Class
Level One Criteria
Level Two Class
Level Two Criteria
Forest
>40% Trees, crowns are interlocking
Main Deciduous
>50% Trees are Deciduous
Mainly Evergreen
>50% Trees are Evergreen
Mainly Xeromorphic
Trees adapted to dry conditions
Woodland
>40% Trees, crowns are not interlocking
Main Deciduous
>50% Trees are Deciduous
Mainly Evergreen
>50% Trees are Evergreen
Mainly Xeromorphic
Trees adapted to dry conditions

Table LAND-P-4: MUC Level 1 –4

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover				
0 Closed Forest	01 Mainly Evergreen Forest	011 Tropical Wet (Rain) Forest	0111 Lowland forest	
			0112 Submontane forest	Costa Rica: Atlantic slope
			0113 Montane forest	Costa Rica: Sierra de Talamanca
			0114 "Subalpine" forest	
			0115 Cloud forest	Jamaica: Blue Mountains
		012 Tropical and Subtropical Evergreen Seasonal	0121 Lowland forest	
			0122 Submontane forest	
			0123 Montane forest	
			0124 "Subalpine" forest	
		013 Tropical and Subtropical Semi-deciduous	0131 Lowland forest	*Ceiba spp.*
			0133 Montane or cloud forest	
		014 Subtropical Wet Forest	0141 Lowland forest	Queensland, Australia, and Taiwan
			0142 Submontane forest	
			0143 Montane forest	
			0144 "Subalpine" forest	
			0145 Cloud forest	
		015 Temperate and Subpolar Evergreen Wet Forest	0151 Temperate evergreen wet forest	Chilean Coast
			0152 Subpolar evergreen wet forest	
		016 Temperate Evergreen with Deciduous Broad-leaved	0161 Lowland forest	
			0162 Submontane forest	
			0163 Montane forest	
			0164 "Subalpine" forest	
		017 Winter-Rain Evergreen Broad-leaved Sclerophyllous	0171 Lowland and submontane	*Eucalyptus regnans, E. diversicolor*
			0172 Lowland and subm. <50m tall	USA: California live-oak forest
		018 Tropical and Subtropical Evergreen Needle-leaved	0181 Lowland and submontane	*Pinus spp. forest of Honduras and Nicaragua*
			0182 Montane and subalpine	*Pinus spp. forest of Phillippines and southern Mexico*
		019 Temperate and Subpolar Evergreen Needle-leaved	0191 Giant forest (>50 m)	*Sequoia and Pseudotsugaspp., Pacific W. of N. America*
			0192 (Irregularly) Rounded crowns	*Pinus spp.*
			0193 Conical crowns	*Picea and Abies spp.: USA California Red Fir forests*
			0194 Cylindrical crowns	Boreal, short branches

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Table LAND-P-4: MUC Level 1 –4 (continued)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover				
0 Closed Forest	02 Mainly Deciduous Forest	021 Tropical and Subtropical Drought-deciduous	0211 Broad-leaved lowland and submontane	Northwest Costa Rica
			0212 Montane and cloud forest	Northern Peru
		022 Cold-deciduous Forest with Evergreen Trees and Shrubs	0221 With evergreen broad-leaved trees and climbers	Western Europe: Ilex aquifolium, Hedera helix North America: Magnolia spp. Northeastern US: maple-hemlock forest
			0222 With evergreen needle-leaved trees	
		023 Cold-deciduous Forest without Evergreen Trees	0231 Temperate lowland and submontane broad-leaved	
			0232 Montane or boreal	
			0233 Subalpine or subpolar	Grades into woodland
	03 Extremely Xeromorphic (Dry) Forest	031 Sclerophyllous-dominated		
		032 Thorn-forest	0321 Mixed deciduous-evergreen	
			0322 Purely deciduous	
		033 Mainly Succulent Forest		
1 Woodland	11 Mainly Evergreen	111 Evergreen Broad-leaved		
		112 Evergreen Needle-leaved	1121 Rounded crowns	*Pinus spp.*
			1122 Conical crowns prevailing	Mostly subalpine
			1123 Narrow cylindrical crowns	Boreal regions: Picea spp.
	12 Mainly Deciduous	121 Drought-deciduous	1211 Broad-leaved lowland and submontane	
			1212 Montane and cloud forest	
		122 Cold-deciduous with Evergreens	1221 With evergreen broad-leaved trees and climbers	
			1222 With evergreen needle-leaved trees	
		123 Cold-deciduous without Evergreens	1231 Broad-leaved deciduous	
			1232 Needle-leaved deciduous	
			1233 Mixed deciduous	
	13 Extremely Xeromorphic (Dry)	131 Sclerophyllous-dominated		
		132 Thorn-forest	1321 Mixed deciduous-evergreen	
			1322 Purely deciduous	
		133 Mainly Succulent Forest		

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Table LAND-P-4: MUC Level 1 –4 (continued)

	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover	2 Shrubland	21 Mainly Evergreen	211 Evergreen Broad-leaved	2111 Low bamboo thicket	
				2112 Evergreen tuft-tree	Mediterranean dwarf-palm, Hawaiian tree-fern
				2113 Broad-leaved hemisclerophyllous	Subalpine Rhododendron thickets, or Hibiscus tiliaceus matted thickets of Hawaii, USA
				2114 Broad-leaved sclerophyllous	Chapparral or macchia
				2115 Suffruticose thicket	*Cistusheath*
			212 Evergreen Needle-leaved and Microphyllous	2121 Evergreen needle-leaved	*Pinus mughus, "Krummholz"*
				2122 Evergreen microphyllous	Tropical subalpine
		22 Mainly Deciduous	221 Drought-deciduous Mixed with Evergreen Woody Plants		
			222 Drought-deciduous without Evergreens		
			223 Cold-deciduous	2231 Temperate deciduous	
				2232 Subalpine or subpolar	
		23 Extremely Xeromorphic (Dry)	231 Mainly Evergreen	2311 Evergreen subdesert	
				2312 Semi-deciduous subdesert	Australia, N. America: Atriplex-Kochia-saltbush
			232 Deciduous Subdesert	2321 Without succulents	
				2322 With succulents	
	3 Dwarf-Shrubland	31 Mainly Evergreen	311 Evergreen Dwarf-shrub Thicket	3111 Caespitose thicket	*Calluna heath*
				3112 Creeping or matted thicket	*Loiseleuria heath*
			312 Evergreen Dwarf-shrubland	3121 Evergreen cushion	E. Mediterranean: Astragalus and Acantholimonspp.
			313 Mixed Evergreen and Herbaceous Formation	3131 True evergreen & herbaceous mixed	*Nardus-Calluna heath*
				3132 Partial evergreen & herbaceous mixed	Greece: Phryganaspp.
		32 Mainly Deciduous	321 Facultative Drought-deciduous		
			322 Obligate Drought-deciduous	3221 Drought-deciduous caespitose	
				3222 Drought-deciduous creeping or matted	
				3223 Drought-deciduous cushion	
				3224 Drought-deciduous mixed	
			323 Cold-deciduous	3231 Drought-deciduous caespitose	
				3232 Drought-deciduous creeping or matted	
				3233 Drought-deciduous cushion	
				3234 Drought-decidunus mixed	

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Table LAND-P-4: MUC Level 1 –4 (continued)

	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover	3 Dwarf-Shrubland	33 Extremely Xeromorphic	331 Mainly Evergreen	3311 Evergreen subdesert	
				3312 Semi-deciduous subdesert	
			332 Deciduous Subdesert	3321 Without succulents	
				3322 With succulents	
		34 Tundra	341 Mainly Bryophyte	3411 Caespitose	
				3412 Creeping or matted	
			342 Mainly Lichen		
	4 Herbaceous Vegetation	41 Tall Graminoid	411 With Trees Covering 10-40 %	4110 Trees: needle-leaved evergreen	
				4111 Trees: broad-leaved evergreen	
				4112 Trees: broad-leaved semi-evergreen	
				4113 Trees: broad-leaved deciduous	
			412 With Trees < 10 %	4120 Trees: needle-leaved evergreen	
				4121 Trees: broad-leaved evergreen	
				4122 Trees: broad-leaved semi-evergreen	
				4123 Trees: broad-leaved deciduous	
				4124 Tropical or subtropical with trees and shrubs in tufts on termite nests	Termite savannah
			413 With Shrubs	4130 Shrubs: needle-leaved evergreen Shrubs:	
				4131 broad-leaved evergreen	
				4132 Shrubs: broad-leaved semi-evergreen	
				4133 Shrubs: broad-leaved deciduous	
				4134 Tropical or subtropical with trees & shrubs in tufts on termite nests	Termite savannah
			414 With Tuft Plants (usu. palms)	4141 Tropical with palms	Bolivia: Arocomia totai and Attalea princeps
			415 Without Woody Synusia	4151 Tropical	Low-latitude Africa, lower Amazon, upper Nile
		42 Medium Tall	421 With Trees Covering 10-40 %	4210 Trees: needle-leaved evergreen Trees:	
				4211 broad-leaved evergreen	
				4212 Trees: broad-leaved semi-evergreen	
				4213 Trees: broad-leaved deciduous	
			422 With Trees < 10 %	4220 Trees: needle-leaved evergreen Trees:	
				4221 broad-leaved evergreen	
				4222 Trees: broad-leaved semi-evergreen	
				4223 Trees: broad-leaved deciduous	
				4224 Tropical or subtropical with trees & shrubs in tufts on termite nests	Termite savannah

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Table LAND-P-4: MUC Level 1 –4 (continued)

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
4 Herbaceous Vegetation	42 Medium Tall	423 With Shrubs	4230 Shrubs: needle-leaved evergreen Shrubs:	
			4231 broad-leaved evergreen	
			4232 Shrubs: broad-leaved semi-evergreen	
			4233 Shrubs: broad-leaved deciduous	
			4234 Tropical or subtropical with trees & shrubs in tufts on termite nests	Termite savannah
			4235 Woody synusia of deciduous thorny shrubs	
		424 Open Synusia of Tuft Plants	4241 Subtropical with open palm groves	
		425 Without Woody Synusia	4251 Mainly sod grasses	USA, Eastern Kansas: tall-grass prairie
			4252 Mainly bunch grasses	New Zealand: Festuca novae-zelandiae
	43 Short Graminoid	431 With Trees Covering 10-40 %	4310 Trees: needle-leaved evergreen Trees:	
			4311 broad-leaved evergreen	
			4312 Trees: broad-leaved semi-evergreen	
			4313 Trees: broad-leaved deciduous	
		432 With Trees < 10 %	4320 Trees: needle-leaved evergreen Trees:	
			4321 broad-leaved evergreen	
			4322 Trees: broad-leaved semi-evergreen	
			4323 Trees: broad-leaved deciduous	
			4324 Tropical or subtropical with trees & shrubs in tufts on termite nests	Termite savannah
		433 With Shrubs	4330 Shrubs: needle-leaved evergreen Shrubs:	
			4331 broad-leaved evergreen	
			4332 Shrubs: broad-leaved semi-evergreen	
			4333 Shrubs: broad-leaved deciduous	
			4334 Tropical or subtropical with trees & shrubs in tufts on termite nests	Termite savannah
			4335 Woody synusia of deciduous thorny shrubs	
		434 Open Synusia of Tuft Plants	4341 Subtropical with open palm groves	
		435 Mainly Bunch Grasses with Woody Synusia	4351 Tropical alpine with tuft plants	
			4352 Tropical alpine, but very open, with no tuft plants	
			4353 Tropical or subtropical with open stands of evergreens	
			4354 With dwarf-shrubs	
		436 Without Woody Synusia	4361 Short-grass communities	USA, Colorado: short-grass prairie
			4362 Bunch-grass communities	
		437 Short to Medium Tall Mesophytic Communities	4371 Sodgrass communities	N. America, Eurasia: Low altitude, cool, humid
			4372 Alpine, subalpine meadows	High latitudes

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Table LAND-P-4: MUC Level 1 –4 (continued)

	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	NOTES AND EXAMPLES
Natural Cover	4 Herbaceous Vegetation	44 Forb Vegetation	441 Tall Forb Communities	4411 Fern thickets	
				4412 Mainly annual forbs	
			442 Low Forb Communities	4421 Mainly perennial flowering forbs and ferns	
				4422 Mainly annual forbs	
	5 Barren Land	51 Dry Salt Flats			
		52 Sandy Areas			
		53 Bare Rock			
		54 Perennial Snowfields			
		55 Glaciers			
		56 Other			
	6 Wetland	61 Riverine			
		62 Palustrine			
		63 Estuarine			
		64 Lacustrine			
	7 Open Water	71 Freshwater			
		72 Marine			
Developed Cover	8 Cultivated Land	81 Agriculture	811 Row Crop or Pasture		
			812 Orchard or Horticulture		
			813 Confined Livestock feeding		
			814 Other Agriculture		
		82 Non-agriculture	821 Parks and Athletic fields		
			822 Golf Courses		
			823 Cemeteries		
			824 Other Non-agriculture		
	9 Urban	91 Residential			
		92 Commercial/Industrial			
		93 Transportation			
		94 Other			

Sources: UNESCO, 1973 and GLOBE, 1996

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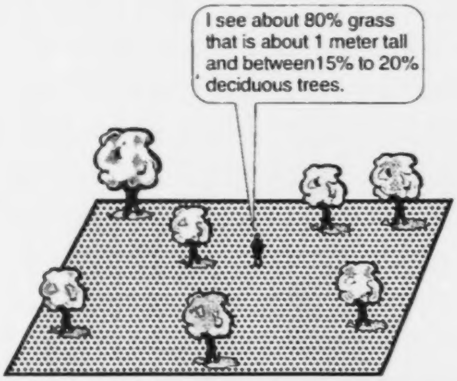
Additional Examples of How to Use the MUC System

The following examples demonstrate the classification process. Refer to the MUC outline (Table LAND-P-4), and to the MUC Glossary in the *Appendix* as you read them.

Example 1

For your Land Cover Sample Site (90 m x 90 m) you pick a relatively homogeneous area of grasses. About 80% of the site is covered by grass and herbaceous plants about 1 meter tall (a 75/25 mix, respectively), and about 15-20% by broad-leaved deciduous trees.


I see about 80% grass that is about 1 meter tall and between15% to 20% deciduous trees.

Level 1: You see on the MUC Classification that class 4, Herbaceous Vegetation is probably the appropriate level 1 class. In the MUC Glossary, you see that class 4 requires greater than 60% total ground coverage of herbaceous vegetation over the entire study site, confirming that class 4 is appropriate.

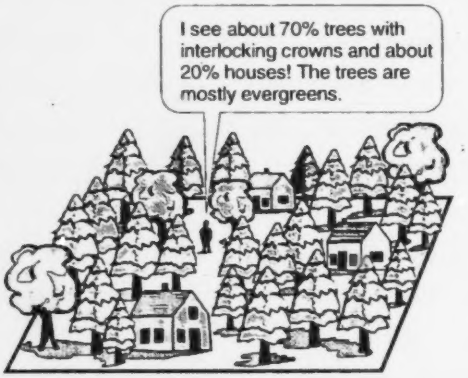
Level 2: On the *MUC Classification*, you now see four choices at level 2 (41-44). After reviewing the definitions of these four classes in the MUC Glossary, you determine that, since the dominant cover type (herbaceous) is more than 50% grass, the level 2 cover type must be Graminoid. Since the grass is between 50 cm and 2 m tall, you select class 42, Medium Tall Graminoid.

Level 3: On the *MUC Classification*, you now have five Level 3 choices (421-425). Since trees cover 15-20% of the study site, you select Class 421, "With trees covering 10-40%", confirming this selection with the MUC Glossary definition.

Level 4: You now have three choices at Level 4 (4211-4213). Since the trees are broad-leaved deciduous, you select class 4213, and you have completed your MUC level 4 classification.

Example 2

You live in a lowland temperate region. You select a Land Cover Sample Site that is mostly forested with the tree crowns touching each other, but about 20% of the ground area has houses on it. Of the trees, it looks like there are more evergreen than deciduous trees, probably a 60/40 split.


I see about 70% trees with interlocking crowns and about 20% houses! The trees are mostly evergreens.

Level 1: On the *MUC Classification* you check your Level 1 choices and find that, since the tree crowns are interlocking, and there is more than 40% canopy cover over the entire study site, Closed Forest, class 0, is the level 1 class.

Level 2: You now have three level 2 choices (01-03). Since at least 50% of the trees that reach the canopy are evergreen, you select class 01, Mainly Evergreen at level 2.

Level 3: You now have nine level 3 choices (011-019), but five are explicitly tropical and subtropical. A sixth choice is a winter-rain category which is also clearly not appropriate. So you have only three categories to seriously consider (015, 016, 019), and after consulting the MUC Glossary you select 016, Temperate Evergreen with Deciduous Broad-leaved.

Level 4: Now you have four level 4 choices (0161-0164). Since you live in a lowland area, class 0161, Lowland forest is the appropriate selection.

How to Classify Land Cover Using the MUC System

When classifying land cover using the MUC system, always begin with the most general classes (level 1) and proceed sequentially to the more detailed (higher level) classes. There are ten level 1 land cover classes in MUC. Eight of these choices are natural land cover and two are developed. At no other level in the MUC system are there more than six land cover choices, and therefore, the level 1 choice among ten classes is the most challenging decision to make. However, given that these ten classes are the most general, the distinctions among them are broad and the decision as to which level 1 land cover class to pick is usually not difficult. Always refer to the definitions for each land cover class to help you in choosing the appropriate class at every level.

How to Classify Land Cover to MUC Level 1

Step 1: Eliminate as many MUC level 1 classes as possible.

- ☐ Compare the Land Cover Sample Site with the definitions of the 10 MUC level 1 classes.
- ☐ Usually there are only a few level 1 classes that can possibly match your site; eliminate the others from consideration.

Step 2: Make any measurements necessary to determine the MUC level 1 class.

- ☐ Perform measurements of tree height, canopy cover, or ground cover and identify dominant and co-dominant species as necessary to distinguish between different MUC level 1 classes. Follow the appropriate portions of the Biometry Protocol. In many cases no measurements will be necessary.
- ☐ Using the quantitative measurements, resolve any questions and assign a MUC level 1 class to this site.

Step 3: Check your assignment.

Read the definitions for the MUC levels 2, 3, and 4 for your chosen MUC level 1 class that are possible for your area. If none of the definitions of higher level MUC classes match your site, reconsider your choice of MUC level 1 class in Step 2.

How to Classify Land Cover Sample to MUC levels 2, 3, and 4

Step 1: Determine the MUC level 2 class.

- ☐ Review the level 2 definitions that apply to the MUC level 1 class of your site.
- ☐ Select the MUC level 2 class that applies to your site.
- ☐ If necessary, make measurements of the vegetation on your site to resolve quantitative distinctions between different level 2 classes using the procedures given in Using Field Observations to Determine MUC Class.

Step 2: Determine the MUC level 3 class.

- ☐ Review the level 3 definitions that apply to the MUC level 2 class of your site. If there are none, record your MUC level 2 class (two digits); you have completed this protocol.
- ☐ Select the MUC level 3 class that applies to your site.
- ☐ If necessary, make additional measurements of the vegetation on your site to resolve quantitative distinctions between different level 3 classes using the procedures given in *Using Field Observations to Determine MUC Class.*

Step 3: Determine the MUC level 4 class.

- ☐ Review the level 4 definitions that apply to the MUC level 3 class of your site. If there are none, record your MUC level 3 class (three digits); you have completed this protocol.
- ☐ Select the MUC level 4 class that applies to your site.
- ☐ If necessary, make additional measurements of the vegetation on your site to resolve quantitative distinctions between different level 4 classes using the procedures given in *Using Field Observations to Determine MUC Class.*
- ☐ Record your MUC level 4 class.

Using Field Observations to Determine MUC Class

Distinguishing among some MUC classes requires quantitative measurements of the percentage of your site that is covered by different types of vegetation. This can be accomplished using modified versions of the Canopy and Ground Cover measurement procedures of the *Biometry* Protocol. You can identify the appropriate MUC class by calculating the percentages of the vegetation types observed at the Land Cover Sample Site. Use the *Dominant/Co-Dominant Vegetation Data Work Sheet* to add up your canopy and/or ground cover observations. You can calculate percentages of deciduous and evergreen canopy cover, and graminoid and forb ground cover in addition to the total canopy cover and green, brown, and total ground cover measurements presented in the Biometry Protocol.

Determining the Percentage of Tree Cover That Is Evergreen or Deciduous

Step 1: Make a modified canopy cover measurement.

- ❑ Repeat the canopy cover measurement from the Biometry Protocol but at each location note "E" if the canopy touching the crosshairs is part of an evergreen tree and "D" if the canopy touching the crosshairs is part of a deciduous tree.

Step 2: Calculate the percentage of the canopy that is evergreen or deciduous.

- ❑ Divide the number of E observations (or D observations) by the sum of the E's and the D's and multiply by 100. If the percentage of evergreen species is greater than 50%, then the site is considered mainly evergreen.

Determining the Composition of Herbaceous Coverage:

Step 1: Make a modified measurement of ground cover.

- ❑ Repeat the ground cover measurement from the Biometry Protocol, but instead of noting whether vegetation is green or brown, note whether it is graminoid (grass) or forb (broad leafed) and record a "GD" if the vegetation under foot or touching the ankle or leg below the knee is a graminoid and an "FB" if it is a forb.

Step 2: Calculate the percentage of ground cover that is graminoid or forb.

- ❑ Divide the number of GD measurements (or FB measurements) by the sum of the GD's and FB's and multiply by 100 to obtain a percentage. If the percentage of graminoid species is greater than 50%, then the sample is considered graminoid. Conversely, if the percentage of forb is greater than 50%, then the sample is considered forb.

$$\%\ \text{Evergreen} = \frac{\#\ \text{of E's (evergreen observations)}}{\#\ \text{of E's} + \#\ \text{of D's (total canopy cover observations)}} \times 100$$

$$\%\ \text{Graminoid} = \frac{\#\ \text{of GD's (Graminoid Observations)}}{\#\ \text{of GD's} + \#\ \text{of FB's (Total \# of Herbaceous Ground Observations)}} \times 100$$

Determining Total Shrub Canopy Cover

If your site or area is one where the dominant land cover types is naturally occurring shrubland or dwarf shrubland (ornamental and cultivated shrubs do not count), you should slightly modify one of the preceding procedures. The equations for canopy cover percentage can be adapted to determine the total shrub canopy cover as well as the percentage of evergreen and deciduous shrubs.

Step 1: Determining the Amount of Shrub Cover

☐ If the canopy of the shrub cover is over head, carry out the canopy cover measurement from the Biometry Protocol. If the canopy cover touching the crosshairs is shrub record "SB", if it is a deciduous tree record "D", and if it is an evergreen tree record "E". If the shrubs are too short to make true canopy observations (i.e. they are too short to walk under), treat the shrubs as an additional ground cover category along with graminoid and forb. Carry out the ground cover measurement from the Biometry Protocol, recording "GD" if the vegetation touching the observer's body at any height is a graminoid, "FB" if the vegetation is a forb, and "SB" if it is a shrub.

Step 2: Calculate the Percentage of Shrub Cover

☐ If the shrub cover is over head, divide the number of SB measurements by the sum of the SB, D, and E measurements. If the shrubs are not overhead, divide the number of SB measurements by the sum of the SB, GD, and FB measurements. Multiply by 100 to obtain a percentage.

References

A land use and land cover classification system for use with remote sensor data. J.R. Anderson, E.E. Hardy, J.T. Roach, and R.E. Witmer. U.S. Geol. Surv. Prof. Pap., 1976.

Classification of wetlands and deepwater habitats of the United States. L.M. Cowardin, V. Carter, F.C. Golet, and E.T. LaRoe. U.S. Fish and Wildl. Serv. FWS/OBS-79/31, 1979.

International classification and mapping of vegetation. United Nations Educational, Scientific and Cultural Organization. Switzerland: UNESCO, 1973.

NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation. J.E. Dobson et al. NOAA Technical Report NMFS 123, 1995.

$$\%\ \text{Shrub} = \frac{\#\ \text{of SB's (Shrub Observations)}}{\#\ \text{of SB's} + \#\ \text{of E's} + \#\ \text{of O's (Total canopy cover observations)}} \times 100$$

OR

$$\%\ \text{Shrub} = \frac{\#\ \text{of SB's (Shrub Observations)}}{\#\ \text{of SB's} + \#\ \text{of GD's} + \#\ \text{of FB's (Total ground cover observations)}} \times 100$$

Manual Interpretation Land Cover Mapping Protocol

Purpose

To produce a land cover map of your 15 km x 15 km GLOBE Study Site

Overview

Students visually interpret what they see in natural color and false color IR prints of the Landsat TM image of their GLOBE Study Site to create a hand-made land cover map of the area. The information on these maps, including MUC level 4 classifications, will help scientists check the accuracy of satellite derived land cover maps worldwide.

Time

Several class periods.

Level

All

Frequency

One time, but may be an iterative process as you progressively investigate more areas within your GLOBE Study Site.

Key Concepts

- Land Cover classes
- MUC Classification scheme

Skills

- *Interpreting* land cover manually

Materials and Tools

- 512 X 512 false color IR print of your GLOBE Study Site (provided by GLOBE)
- 512 X 512 natural color print of your GLOBE Study Site (provided by GLOBE)
- Topographic maps of your area
- MUC Land Cover Classification System Table LAND-P-5 and definitions in the *Appendix*
- Color photocopier (if available)
- Clear plastic sheets or blank transparencies
- Tape
- Felt-tipped markers
- *Manual Classification Tutorial* in the *Toolkit*

Preparation

Review the MUC Land Cover Classification Chart, discuss and evaluate local land covers, review topographic maps, and discuss classification.

Prerequisites

Odyssey of the Eyes and *Some Like it Hot Learning Activities*

With this method, students use *image interpretation* - they visually interpret what they see in a print of their local TM image. This method may be less accurate than others because personal interpretation is subjective. Students identify and outline areas of different land cover class. Usually, water bodies will be easiest to identify, although cloud shadows sometimes resemble lakes and ponds. Others will be harder to distinguish. For example, hardwood forests may look spectrally similar to actively growing fields. The *false color* IR image makes bodies of water and vegetation types easier to distinguish, while other types of land cover may be easier to see on the natural color image. In areas on the images where you can not identify the type of land cover, you will need to field-check the areas using the *Qualitative* or *Quantitative Land Cover Sample Site Protocols*. Assign all land cover classes using the MUC system. For further information, see the *Manual Classification Tutorial* in the *Toolkit*.

Note: The remote sensing image you use may be a few years old. Land cover may have changed since the image was taken. What you identify on the Landsat TM image may be different than what you see in your ground assessments. In this case, students should work to determine what was on the site at the time the satellite made the image.

Step 1: Create Your Land Cover Map

- ☐ Give students the false color IR print of the Landsat TM image of your GLOBE Study Site. Generally, each color on the IR map represents a different land cover class.
  Red represents actively growing, green vegetation (bright red represents hardwoods and fields, dark red represents evergreens).
  Black represents water.
  Blue represents urban areas and bare soils.
- ☐ Since the original print of your area provided by GLOBE is usually approximately 25 cm x 25 cm, try to enlarge various sections of it on a color copier to several times their original size. Four or more small groups of students can work on different enlarged portions of the original scene.
- ☐ Take a sheet of clear plastic large enough to cover your image. Place the plastic on top of the image and hold it in place with tape. Mark the location of the image corners on the plastic so it can be placed back in the same position if it is removed.
- ☐ Using felt-tipped marking pens, carefully outline areas of similar land cover class. Use a different color to represent each type. Assign each type the appropriate number from the MUC Land Cover Classification Chart. See Table LAND-P-5: MUC Level 1-4. If a group cannot identify a specific area, have a group or class discussion to try to identify it. Also ask a student living near the unidentified area to make an assessment of the land cover class from the MUC system on the way to or from school (students can return to such a site later and complete the *Qualitative* or *Quantitative Land Cover Assessment Protocols*). Students must be careful and specific when outlining areas and assigning classes. Start by identifying the most obvious features - usually bodies of water and urban areas - and then progress to more difficult types, such as different types of natural vegetation cover.
- ☐ Once each group has mapped their image section, combine the sections and compare results in order to identify problem areas. For instance, one group may identify an area in their section as "class 1192" (needle-leafed evergreen woodland), while a group mapping an *adjacent* section identifies their portion as "class 1222" (mixed deciduous and evergreen woodland).

Step 2: Report your results

- ☐ Once you identify all the areas on your image, transfer all MUC identifications onto a master copy and submit them to the address given in the *Implementation Guide*.

Unsupervised Clustering Land Cover Mapping

Purpose

To produce a land cover map of your 15 km x 15 km GLOBE Study Site

Overview

Students map land cover using a computer to recognize similar *spectral patterns* within the digital, 512 x 512 pixel Landsat Thematic Mapper data set provided by GLOBE for their GLOBE Study Site. These maps, classified to MUC level 4, will help scientists check the accuracy of worldwide land cover maps derived from satellite imagery.

Time

Several class periods

Level

Intermediate and Advanced

Frequency

One time, but may be an iterative process as you progressively investigate more areas within your GLOBE Study Site

Key Concepts

Land Cover classes
MUC Classification scheme
Clustering using spectral patterns

Skills

Using computers and MultiSpec software
Creating a land cover map

Materials and Tools

Computer

MultiSpec computer software (provided by GLOBE or downloaded from the Web)
512 x 512 pixel TM image data of your 15 km x 15 km GLOBE Study Site (provided by GLOBE)
MUC Land Cover Classification System and definitions

Preparation

Review the MUC Land Cover Classification Chart. Discuss and evaluate local examples of land cover, review topographic maps, and discuss classification.

Review the *MultiSpec Introduction to Image Processing* and *Unsupervised Classification - Clustering* in the *Toolkit*

Prerequisites

Odyssey *of the Eyes* and *Some Like it Hot Learning Activities*

In this protocol, GLOBE schools use the MultiSpec software to map land cover types. Students tentatively identify areas of similar land cover using the computer to recognize similar *spectral patterns* within the digital, 512 x 512 pixel Landsat TM data set for their area. These areas are grouped into *clusters*. The computer identifies and clusters together pixels in the image which have the most similar spectral properties. The software assigns each cluster an arbitrary color. Students then classify the land cover type of each cluster using the four levels of the MUC system.

Step 1: Create Your Map

- ☐ Start the MultiSpec program on your computer.
- ☐ Open the file containing the TM image of your GLOBE Study Site.
- ☐ Create a new project and select **Cluster** from the **Processor** menu.
- ☐ Select the appropriate number of clusters according to the number of groups you wish to classify (10 is recommended). Provide the system with other information as directed in the MultiSpec tutorial

section on Unsupervised Classification: Clustering.

- ☐ Once the image has been clustered, note the area included in each cluster. If you know the land cover of an area, assign a land cover class from the MUC system to the cluster. If you do not know the land cover of an area, use the data from a Land Cover Sample Site within the area to assign the land cover class from the MUC system. If there are no Land Cover Sample Sites within the area of a cluster, perform the *Qualitative* or *Quantitative Land Cover Protocol* for a site within this area. If there are multiple sample sites within an area, use only one of these sites to make the land cover class assignment and reserve the others for use in the *Accuracy Assessment Protocol*.
- ☐ Rename each cluster to correspond with its appropriate MUC Level 4 classification.

Step 2: Save Your Image and Report Data

- ☐ **Save** the classified clustered image. Use the **Project** menu to copy it onto a disk as a TIFF file. If you have a color printer, print copies of your students' land cover map(s).
- ☐ Report your data to the GLOBE Student Data Archive by sending a copy of the TIFF containing your classified, clustered map. Use the address given in the *Implementation Guide*.

Accuracy Assessment Protocol

Purpose

To quantitatively assess the accuracy of a land cover map

To identify the types of errors that occur on a land cover map

Overview

Students will perform an accuracy assessment on the land cover map they have generated either by manually interpreting or unsupervised clustering of the Landsat Thematic Mapper image of their GLOBE Study Site. Validation data collected at various Land Cover Sample Sites, which were not used in the development of the map, will be used to compare with the land cover map, and a difference/error matrix will be generated.

Time

Approximately 2 hours depending on the number of validation samples collected

Level

All

Frequency

Once for each land cover map. The accuracy assessment can be repeated when more validation sites have been measured; the statistical validity of the accuracy assessment improves as more samples are used.

An accuracy assessment can be performed on only a portion of the map.

Key Concepts

Accuracy assessment allows evaluation of our ability to map land cover.

The difference/error matrix

Skills

Building and *analyzing* a difference/error matrix for accuracy assessment

Solving problems cooperatively to resolve accuracy issues

Materials and Tools

Natural color, hard-copy TM image of your 15 km x 15 km GLOBE Study Site

False color infra-red, hard-copy TM image of your 15 km x 15 km GLOBE Study Site

MUC classification work sheet

Difference/error matrix work sheet

Preparation

Have copies of the necessary Work Sheets so the students can quickly compare the Land Cover Sample Sites to the appropriate location on the land cover map and generate the difference/error matrix.

Prerequisites

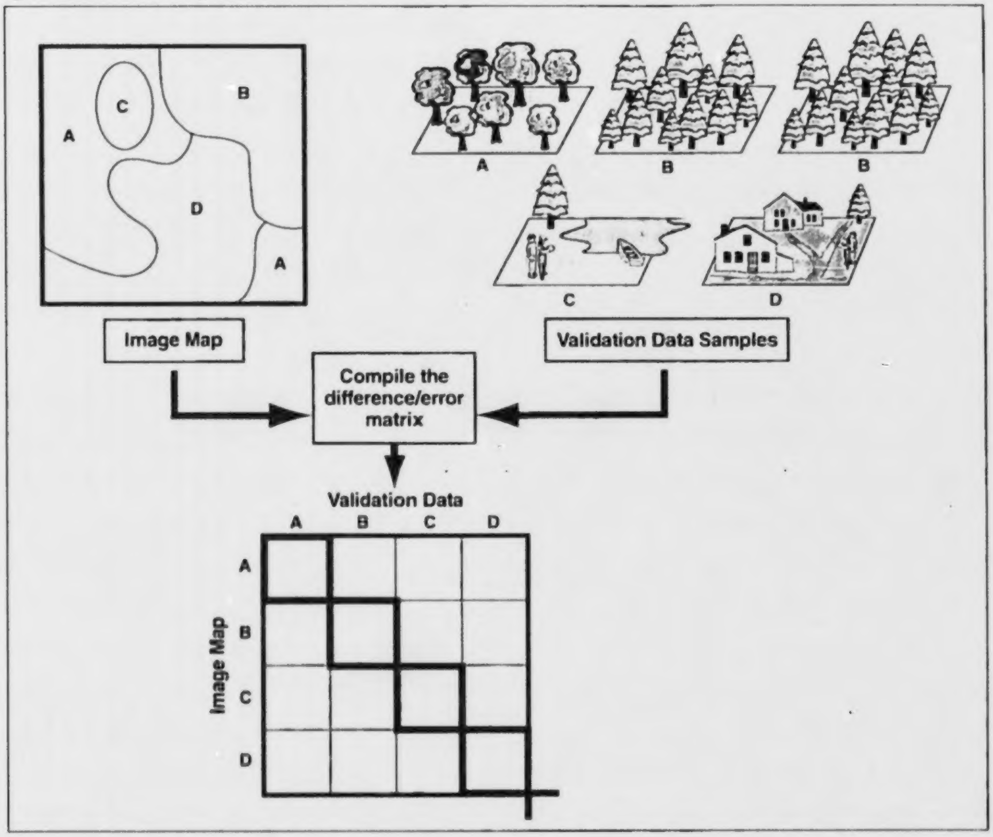
Either of the *Land Cover Mapping Protocols*

Introducing the Difference/Error Matrix Learning Activity

Introduction

In this protocol students will assess the accuracy of the land cover map generated from the remotely sensed data. See Figure LAND-P-18. It does not matter whether the land cover map was created through manual interpretation of an image or generated using the MultiSpec software and unsupervised clustering. In both cases, it is still important to compare the land cover map to Land Cover Sample Sites measured on the ground. A difference/error matrix will be generated to serve as a framework for analyzing the errors which occur in the land cover map. In the case of a land cover map generated from a satellite image using

Figure LAND-P-18: Accuracy Assessment Process



unsupervised clustering, some of the errors may be related to the fundamental limitations of the satellite image data as a tool in distinguishing land cover classes.

The following information is needed to generate a difference/error matrix:

- Land cover map generated from remotely sensed data
- Validation Land Cover Sample Sites

In order to generate a difference/error matrix, it is necessary to have validation data (Land Cover Sample Sites) collected for each land cover type in the Globe Study Site that you wish to assess. Ideally, it would be great to have samples for every land cover type. It may not be possible to collect all these samples and therefore, it may be desirable to only generate the matrix for the 3 or 5 most common types. The more samples collected for each land cover type, the more statistically valid the matrix will be. Over time, every school should be able to collect enough data to generate at least a limited difference/error matrix.

Once the validation data has been collected according to the protocols outlined in the *Qualitative* and *Quantitative Land Cover Sample Site Protocols*, it is possible to begin creating a difference/error matrix. This difference/error matrix should have a row and column for each and every MUC class that is on the MUC Classification Data Work Sheet (i.e. every MUC class that occurs for a land cover sample site or that labels any area on that portion of the land cover map that is being validated). See Table LAND-P-5. In this example there are four MUC classes: code 0222, code 0221, code 1121, and code 811. In the corresponding difference/error matrix (Table LAND-P-6), there is a column and a row for each of these four classes. For sample number 1 on the Example MUC Classification Data Work Sheet (Table LAND-P-5), you look up the Student MUC Classification for this area of the land cover map (Table LAND-P-5 cell A- Mainly cold-deciduous forest with some evergreen needle leafed trees, MUC code 0222 at level 4). In Table LAND-P-6, the Difference/Error Matrix you find the matching in the left-hand column (the first row for MUC Code 0222). For sample number 1 on the Example MUC Classification Work Sheet (Table LAND-P-5), you determine that the validation data from the Land Cover Sample Sites (Table LAND-P-5-cell B) is mainly cold-deciduous forest with evergreen broad leafed trees, MUC code 0221. In Table LAND-P-6 the Difference/Error Matrix, from the cell with the identified Student Classification MUC code 0222, you move along the row (left-to-right) until you find the column with a label which matches the Validation Data MUC code 0221. In the cell at the intersection between the MUC code 0222 row and the MUC code 0221 column, (cell B1), you mark one tally and move to the next sample. In this way, the rows represent the areas of the map and the columns represent the validation data. The overall accuracy is calculated using the procedure illustrated in Table LAND-P-6.

It should be understood that collecting validation data (Land Cover Sample Sites) is a time consuming process; it may take numerous classes to put together enough data for a valid matrix. This is an excellent place within GLOBE to rely on a learning community to cooperate in accomplishing a protocol. Using Qualitative Land Cover Sample Sites will greatly speed up this process; however, scientifically, Quantitative Land Cover Sample Sites are preferred.

How to Tally Validation Data on a Difference/Error Matrix and Calculate Overall Accuracy

Refer to Tables LAND-P-5 and LAND-P-6 to help you understand the following procedures.

Step 1: Preparation

☐ It is important to remember not to look at what you, the student, labeled an area before going out to collect validation data for that same area. Knowing what the image

Table LAND-P-5: Example MUC Classification Data Work Sheet

Sample Number	Site Name	Student Classification on a Land Cover Map	Validation Data from Land Cover Sample Sites	√	X
1	Brown's Woods	A: Mainly cold-deciduous forest with some evergreen needle leafed trees (MUC code 0222)	B: Mainly cold-deciduous forest with evergreen broad leafed trees (MUC code 0221)		X
2	Smith State Park	C: Mainly evergreen woodland with rounded crowns and needled leaves (MUC code 1121)	D: Mainly evergreen woodland with rounded crowns and needled leaves (MUC code 1121)	√	
3	Appleby Farm	E: Pasture (MUC code 811)	F: Pasture (MUC code 811)	√	
4	Green's Woods	G: Mainly cold-deciduous forest with evergreen broad leafed trees (MUC code 0221)	H: Mainly cold-deciduous forest with evergreen broad leafed trees (MUC code 0221)	√	

Table LAND-P-6: Difference /Error Matrix Example

		Validation Data				
		MUC code 0222	MUC code 0221	MUC code 1121	MUC code 811	**Row Total**
Map Classification	MUC code 0222	**A1:**	B1: 1	C1:	D1:	E1: 1
	MUC code 0221	**A2:**	B2: 1	C2:	D2:	E2: 1
	MUC code 1121	**A3:**	B3:	C3: 1	D3:	E3: 1
	MUC code 811	**A4:**	B4:	C4:	D4: 1	E4: 1
	Column Total	**A5: 0**	B5: 2	C5: 1	D5: 1	E5: 4

$$\begin{array}{ccc} E5 = A5 + B5 + C5 + D5 & = & E1 + E2 + E3 + E4 \\ \text{(column total)} & = & \text{(row total)} \end{array}$$

$$\text{Overall Accuracy} = \frac{A1 + B2 + C3 + D4}{E5} \cdot 100 = (3/4) \cdot 100 = 75\%$$

classification says an area is before collecting the validation data biases the collection. Therefore, validation data should be collected on the Data Work Sheet outlined in the Land Cover Sample Site Protocols and then the example Table LAND-P-5 should be created in the classroom after the data has been collected and recorded. Table LAND-P-5 can then be used as the input to create the difference/error matrix. A check is used to represent agreement between the student classification and the validation data while an X denotes a difference.

Step 2: Build an empty difference/error matrix

☐ Build an empty square matrix. There should be a column and row in the matrix for every MUC class that occurs in the validation data or on the portion of the land cover map that is being validated. Label each of the columns and rows of the matrix with one of these MUC classes. Be sure that the labels are in the same order starting from the upper left-hand corner going down and across. Be sure to include a right-hand column and a bottom row for totals

Step 3: Identify student classification from map for sample 1

☐ For a sample on your MUC Classification Work Sheet, look up the Student MUC Classification for the area of the land cover map in which this sample site is found.

Step 4: Find appropriate row in matrix for data

☐ Find the row in your matrix corresponding to the area of the map in which this land cover sample site is located.

Step 5: Identify MUC class from validation data for sample

☐ On your MUC Classification Work Sheet, look up the validation data MUC Classification for this sample site.

Step 6: Find appropriate cell in matrix for data and tally

☐ Move along this row from left to right to the box in the column labeled with the MUC class corresponding to that of the validation data. Mark one tally in this box.

Step 7: Repeat steps 3 through 6 for each sample

☐ Repeat this process for each sample on your MUC Classification Work Sheet. After you have completed tallying all of the samples, calculate the totals for each row and column. If the sum of the row totals does not equal the sum of the column totals, recheck your arithmetic.

Step 8: Calculate overall accuracy

☐ Sum the number of tallies in all the boxes on the major diagonal of the matrix (i.e. the boxes for which the row and column labels are the same) except the lower right-hand total box. Divide this sum by the total number of samples which is equal to the value in the lower right-hand box. Multiply this quotient by 100 to convert it to a percentage. Refer to the example in Table LAND-P-6.

Step 9: Interpret results

☐ Just as the cells along the major diagonal represent all the correct classifications or agreement between the student classification of the map and the validation data collected by students at Land Cover Sample Sites, the cells which are off the major diagonal represent incorrect classifications or the differences. Hence the name difference matrix or error matrix. This information can be used to identify MUC classes that were particularly difficult to classify, and also which MUC classes were confused with each other.

Figure LAND-P-17 presents a difference/error matrix for three broadly generalized land cover categories. This matrix is simply a cross-classification comparing the map categories to the validation data. In the places that agreement occurs, a tally is made along the major diagonal. Differences or errors are represented by the off-diagonal elements of the matrix. In addition to depicting the matrix as a 2 dimensional table, it can also be represented 3 dimensionally. In this case, it is easy to see that the more accurate the map, the bigger the blocks along the major diagonal.

Reporting the Data

Report all difference/error matrices to the GLOBE Student Data Base.

Figure LAND-P-17: A Difference/Error Matrix for Broad Land Cover Categories

		Validation Data			
		F	W	U	Row Total
Classified Data (Map)	F	28	14	15	57
	W	1	15	5	21
	U	1	1	20	22
	Column Total	30	30	40	100

Land Cover Categories

F = Forest
W = Water
U = Urban

Overall Accuracy = 63/100 = 63%

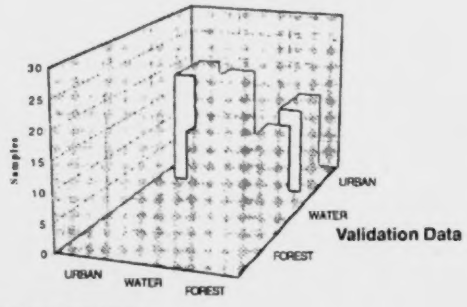
Producer's Accuracy

F = 28/30 = 93%
W = 15/30 = 50%
U = 20/40 = 50%

User's Accuracy

F = 28/57 = 49%
W = 15/21 = 71%
U = 20/22 = 91%

Figure LAND-P-18: A 3-D View of a Difference/Error Matrix



Learning Activities

Leaf Classification

Students make a collection of leaves and then discover how a hierarchical classification system is developed by sorting and organizing their leaves according to a set of labels and rules which they specify.

How Accurate Is it? Introducing the Difference/Error Matrix

Students learn how to evaluate the accuracy of a classification scheme.

What's the Difference?

Students learn how to evaluate the accuracy of a classification scheme.

Odyssey of the Eyes

These beginning, intermediate and advanced level activities will introduce students to modeling as it relates to remote sensing.

Some Like It Hot!

Students will learn about remote sensing, false-colored images and image resolution. This activity is divided into beginning, intermediate and advanced levels.

Discovery Area

This intermediate level activity will help students refine their understanding of remote sensing and mapping.

Site Seeing

Beginning and intermediate level activities introduce students to the concept of dynamic systems.

Seasonal Changes in Your Biology Study Site(s)

Students investigate seasonal changes by collecting data on spring bud-break and fall leave senescence.

Leaf Classification

Purpose

Students will learn to classify (sort) a group of objects into different groups (classes). Students will learn about hierarchical classification systems. These fundamental concepts will help students better understand the MUC scheme used in the GLOBE *Land Cover* and *Accuracy Assessment Protocols*.

Overview

Students will gather an assortment of leaves from the school. As a group, they will develop their own classification system for sorting leaves, and will learn that there are different ways to classify the same group of objects. This activity introduces the complexity of a "simple" task for which there are no truly correct answers.

Time

One class period

Level

All

Key Concepts

Classification helps us organize and understand the natural world.

A classification system is a set of labels and rules used to sort objects.

A hierarchical system has multiple levels of increasing detail.

Skills

Creating a classification scheme

Using the scheme to organize objects

Beginning: *Sorting* and *grouping* objects

Intermediate: *Using* labels and rules in *classifying* objects

Advanced: *Using* detailed labels and rules in *classifying* objects

Materials and Tools

A variety of different leaves

Chalk board or large paper for classification scheme outline

Preparation

Collect a variety of different leaves.

Prerequisites

None

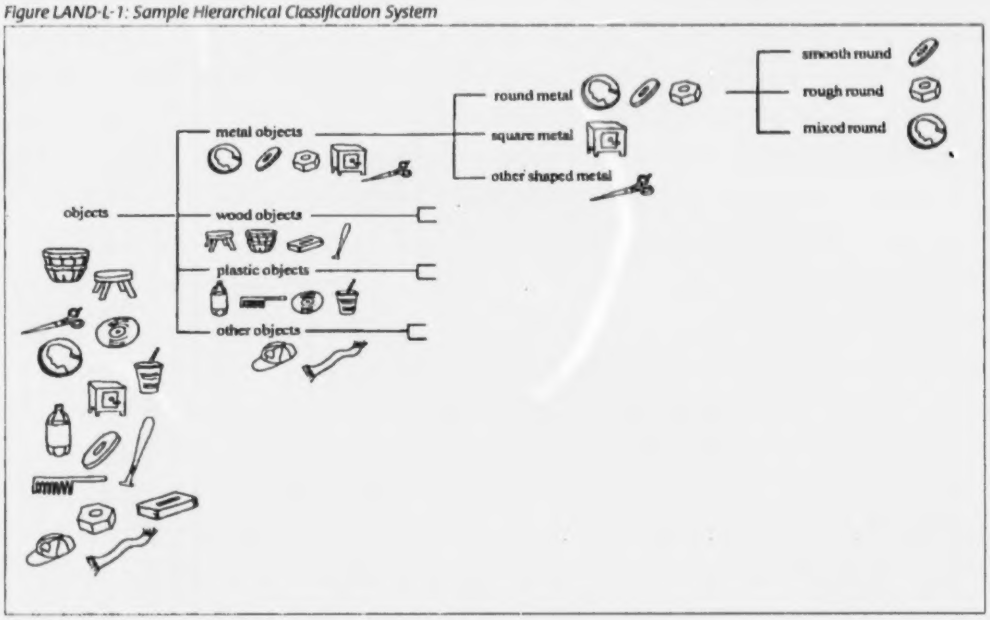
Background

Scientists classify many features of our environment such as clouds, soil types, or forest types. These classifications help us organize and understand the natural world. A *classification system* is an organized scheme for grouping objects into similar categories. There are two components to a classification system: *labels and rules*. The labels are the titles of the different classes in the classification system; the rules are the tests you apply to decide in which class to place an object. Well-defined labels and rules allow scientists to consistently describe and organize objects. For example, the Modified UNESCO Classification System used in the GLOBE protocols allows GLOBE participants to consistently describe the land cover at any point on earth using the same labels and rules as all the other GLOBE participants.

There are several key characteristics of all good classification systems. First, the classes must be *mutually exclusive* - that is, any object must have only one appropriate class in which it can be placed. If a classification system could place a leaf in either of two categories, then the classes are not mutually exclusive. Second, the classification system must be *totally exhaustive* - that is, there must be an appropriate class for all potential objects. This is frequently achieved by having a catch-all class such as "other". If you have a leaf for which there is no appropriate class, then the classification system is not totally exhaustive, and it must be modified, usually by adding at least one more class.

Finally, a classification system should be *hierarchical*. There should be multiple levels of increasing detail. At any level of detail, all the different classes should be able to "collapse" into the next (less detailed) level of the classification system. Figure LAND-L-1 is an example of a hierarchical classification system of objects to illustrate: level one classes are metal objects, wood objects, plastic objects, and objects of other materials; level two classes within metal objects are round metal objects, square metal objects, and other shaped metal objects; level three classes within square metal objects are smooth surfaces, rough surfaces, and mixed surfaces; and so on.

Figure LAND-L-1: Sample Hierarchical Classification System



What To Do and How To Do it

1. Gather a collection of leaves (and bunches of needles) to be sorted into groups - get as many, and as many varieties as possible. Even try to get brown (old) and green (fresh) leaves. Try to make sure there are several conifer and deciduous varieties as well as plant or shrub leaves. If you live in a grassland area, you could use grasses or other herbaceous ground cover.
2. Gather the class in a circle. In the center, on the floor or on a table, spread out all of the leaves.
3. Instruct the students that they have to sort (classify) all of the leaves into groups of similar types. Using a chalkboard to list suggestions, have the students suggest different characteristics that could be used for sorting the leaves. Discuss the difference between labels and rules. Discuss which characteristics are most important - or just have the students vote to decide the order of importance. They should realize that there is not necessarily one correct way. Classification systems are somewhat arbitrary, governed only by what we think makes sense. At the end of this step, you should have several characteristics, in hierarchical order of importance and generality, to be used for sorting the leaves.

Variation: Divide the class into groups and have each perform this step working independently. Then compare the classification systems and discuss the results.

4. Explain to the students that this hierarchical group of characteristics is a classification system. Scientists use classification systems to classify just about everything they encounter in the natural world: animals; trees; clouds; soils; and groups of vegetation associations, e.g., forest, desert, and meadow. Refer to the Accuracy Assessment pre-protocol learning activities for examples of bird and cloud classification.
5. Have the students sort the leaves using the chosen labels and decision rules. As the students sort the leaves, they may find that the classification system has to be modified or refined. This happens frequently in scientific projects. If there is time, students can use several different classification systems for sorting the leaves.

Discussion Questions

1. Why is it important that a classification system be exhaustive, mutually exclusive, and hierarchical?
2. How is it possible that there is no one "correct" classification system for leaves?
3. Do the user's objectives affect the classification system which would be used?
4. Is a more detailed classification system better?

Variations

You can use various assortments of natural or unnatural objects for this exercise. Many things work well. It is useful to use leaves especially with younger students, so that students are comfortable distinguishing conifer and deciduous leaves and needles from each other.

Student Assessment

Assuming that students have participated in an activity "debriefing" using the discussion questions above, they should be able to accomplish the following:

1. Describe the design of their classification system, including the basis for the labels they use to establish different classes of leaves.
2. List rules or decision criteria they use for assigning each leaf to its class.
3. Describe how they structured the hierarchical system.
4. Have classified all of the leaves they collected using their system.

Each level of learners (beginning, intermediate, advanced) is likely to explain their approach using increasingly complex or detailed information and criteria.

The ultimate measure of student's understanding of how classification systems are constructed and used will be the ease with which students are able to use the Modified UNESCO Classification System (MUC).

To determine whether students have grasped the concepts of developing a classification system have them review by answering the following questions:

1. What is a classification system?
2. What labels did you use to identify different classes of leaves?
3. What rules (criteria) did you use to assign each leaf to its class?
4. What are the levels of your classification system?
5. Are all of your leaves identified by assigning them to a class using the multiple layers of your system?

How Accurate Is It? Introducing the Difference/Error Matrix

Purpose

To quantitatively evaluate the accuracy of a classification

Overview

Students will sort birds into three possible classes: carnivores (meat eaters), herbivores (plant eaters), and omnivores (meat and plant eaters) based on the bird's beak. They will then compare their answers with a given set of validation data and generate a difference/error matrix. The students will then discuss how to improve their accuracy based on identifying specific mistakes they made as indicated by the difference/error matrix.

Time

One class period

Level

Intermediate to Advanced

Prerequisites

Basic ability to classify things

Fractions and percentages

Key Concepts

Classification helps us organize and understand the natural world.
In order for classification systems to be useful, we need to quantitatively determine their accuracy.
Criteria are used to define accuracy levels.

Skills

Classifying birds
Evaluating the accuracy of the classification
Improving the accuracy of the classification based on the evaluation
Analyzing data to understand the interrelationships of a classification and its accuracy
Identifying decision criteria for a classification system
Collecting and *interpreting* validation data
Building and *analyzing* a difference/error matrix for accuracy assessment
Solving problems cooperatively to resolve accuracy issues

Materials and Tools

Master set of bird pictures
Master validation sheet
Overhead showing a sample bird classification work sheet
Set of bird pictures
Sample beak sketches
Classification Work Sheet
Difference/Error Matrix Work Sheet

Preparation

Bird picture sets need to be reproduced without the answers on the back. Also student work sheets need to be reproduced for each group.

Background

Scientists classify many features of our environment, such as species of life, forest types, or soil types. These classifications are a fundamental mechanism for helping us to organize and to understand the natural world. There may be several different appropriate ways to classify a set of objects of interest. Two particular objects may be classified differently either because of error on the part of one or both of the classifiers, or simply because different classifying criteria were used. In any case, we need to know how much error is in our classification in order to use the information we have obtained with some confidence in its accuracy. Ultimately, the information generated by the classification of remotely sensed data will be used to make important decisions about global problems such as deforestation, global warming, and environmental degradation. It is very important that we not make these decisions based on information that is inaccurate.

A difference/error matrix is the basic tool used for accuracy assessment of remotely sensed data. It gives us a mechanism for generating a number rating the overall accuracy of a classification or map and provides information about the sources of error. This can focus our attention on those areas or classes that require it. We can use this information to improve the quality of our classification criteria, and to improve our skill at distinguishing those classes for which there is a lot of confusion.

References

Peterson's Field Guide to Birds

Audubon Field Guides

The Illustrated Encyclopedia of Birds: The Definitive Reference to Birds of the World. Consultant-in Chief Dr. C. Perrins. New York: Prentice Hall Press, 1990.

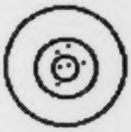
Check local resources for regional guides

Acknowledgment

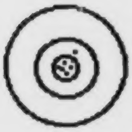
Art by Linda Isaacson

Key Terms and Concepts

accuracy: the degree of conformity to a standard or accepted value. Compare to precision.



The marks on this bull's-eye have high accuracy and low precision



The marks on this bull's-eye have high accuracy and high precision

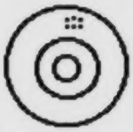
classification: taking a set or group of items and sorting them (classifying them) into well-defined and distinct subsets according to specific criteria. For example, taking a map and outlining areas of evergreen trees, deciduous trees, mixed evergreen and deciduous trees, and non-forest.

criteria: a decision rule. For example, if a forest stand has more than 50% evergreen needles in its canopy, the stand will be classified as evergreen. The preceding definition (e.g., more than 50% evergreen needles) is the *criteria*, the *category* or *class* is evergreen.

dataset: a group of values related to the same question being asked. These values will be analyzed together as a group. For example, the set of the heights of all students in this class would be one dataset.

difference/error matrix: (see the difference/error matrix on the work sheet at the end of this exercise) a table of numbers organized in rows and columns which compares a classification to validation data. The columns represent the validation data while the rows represent the classification generated by students. A difference/error matrix is a very effective way to represent accuracy. Correct and incorrect classifications can be compared for each category and used to improve the accuracy of the original classification.

precision: the closeness of several measures to each other. The repeatability of a measurement. This is a very important part of any scientific operation, but is different from accuracy.



The marks on this bull's-eye have high precision and low accuracy

validation data: data collected with a presumed high degree of accuracy. A classification of items (birds in this exercise) is compared to validation data: 1.) to improve the decision criteria for the classification 2.) to better understand the sources of error in the classification; and 3.) to assess the accuracy of the classification data.

Validation data is often collected to improve the classification of an image generated by some form of remote sensing (aerial photography or satellite imagery). Often the term "ground truth" is used in place of validation data, however, many scientists prefer the term reference or validation data. Data that is gathered on the ground always has some degree of error and thus does not represent the "truth".

◆

Example

The following is an example of a filled in classification work sheet, difference/error matrix, and an overall accuracy calculation.

Table LAND-L-1: Sample Bird Classification Work Sheet

Bird Id#	Student Classification	Validation Data	✔ or x
1	Carnivore	Carnivore	✔
2	Omnivore	Carnivore	x
3	Herbivore	Herbivore	✔
4	Carnivore	Carnivore	✔
5	Herbivore	Herbivore	✔
6	Herbivore	Omnivore	x
7	Omnivore	Omnivore	✔
8	Carnivore	Carnivore	✔
9	Carnivore	Herbivore	x
10	Omnivore	Carnivore	x

Table LAND-L-2: Sample Difference/Error Matrix Work Sheet

Validation Data

Student Data

	Carnivore	Herbivore	Omnivore	Row Total
Carnivore	A1. 3	B1. 1	C1. 0	D1. 4
Herbivore	A2. 0	B2. 2	C2. 1	D2. 3
Omnivore	A3. 2	B3. 0	C3. 1	D3. 3
Column Total	A4. 5	B4. 3	C4. 2	D4. 10

Note: Row and column totals should add up to the same number. Check with others in your group to make sure you counted correctly for each answer in the matrix.

$$D4 = (A4 + B4 + C4) = (D1 + D2 + D3)$$

(column total) (row total)

How to read this information:

Across row one (A1-D1) of this example, three carnivores were correctly identified by the students as carnivores, one herbivore was incorrectly classified as a carnivore and no omnivores were classified as carnivores.

Computing the Accuracy:

$$\text{Overall accuracy} = \frac{\text{sum of major diagonal (A1+B2+C3)}}{\text{total of entire matrix (D4)}}$$

Step 1: Sum the values in the boxes along the major diagonal (A1+B2+C3) shown in Table 4-13: Sample Difference/Error Matrix. This number is the total number of correct classifications. In this example there are six correct classifications out of ten total samples.

(3+2+1) = 6

Step 2: Divide the total number of correct classifications (A1+B2+C3) by the total number of samples (box D4).

6 divided by 10 = 0.6

Step 3: Multiply by 100 for the overall accuracy of the exercise:

0.6 times 100 = 60% accuracy

The calculation can be done for any of the individual categories as well (e.g., 3 out of 5 carnivores were classified correctly). The numbers off the major diagonal represent "incorrect" classifications. Each error or difference is an omission from the correct category and a commission (i.e., an erroneous addition) to the incorrect category.

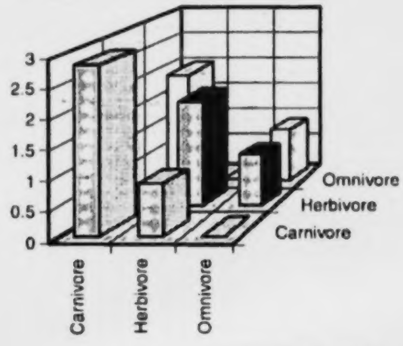
If your answer is between:	Your Level of Expertise is:
0%-50%	Novice
51%-85%	Intermediate
86%-100%	Advanced

The class can also compare fractions (1/2 is less than 3/4, 3/4 is less than 9/10) instead of percentages.

Adaptations

1. A visual interpretation can be used instead of mathematically calculating the overall accuracy. Layout a 3 cell x 3 cell grid on a sheet of paper numbered like the cells in the difference/error matrix.
   Visually represent the number of birds in each box by either graphing or physically stacking blocks in the boxes. The tallest columns should be along the diagonal of the grid.
2. If the class has access to computer spreadsheets, a 3-D graph can be created to represent the answers. Figure LAND-L-2 shows the data from the example difference/error matrix graphed in a 3-D format.
3. The activity may be modified by leading the activity for the whole group and creating one difference/error matrix on the black board.

Figure LAND-L-2: Difference/Error Matrix of Bird Classification Data



Source: GLOBE, 1996

What To Do and How To Do It

1. To prepare your students, discuss with them the following questions:
   - Why do we organize or sort objects into groups?
   - How do we sort these objects?
   - Name three examples of objects that are commonly sorted into groups.
2. Copy and distribute the student work sheets, the bird pictures, the bird beak sketches, the classification work sheet, and the difference error/matrix work sheet.
3. Have your students follow the instructions on the work sheets, to do the following steps:
   - Classifying pictures of birds into three categories.
   - Comparing answers with the reference data provided.
   - Generating a difference/error matrix using the results of the comparison.
4. After your students have completed this activity, discuss the results with your students by asking the following questions:
   - How did different students' results vary?
   - Why do students think this happened?
   - What other classifications might be compared using a difference/error matrix (e.g., maps identifying land cover for a specific location versus carefully checking the same location in person.

Student Activity Guide

Duplicate and distribute to students.

Overview

Scientists classify many features in our environment, such as species of life, forest types or rock types. These classifications, or categories, help us to organize and understand the natural world. In order for these classifications to be useful to scientists, we need to know how accurate they are. A difference/error matrix is the basic tool used to measure the accuracy of a classification procedure. This difference/error matrix also shows us where there was confusion or difficulty classifying certain classes.

In this activity you will:

- Classify pictures of birds into three categories
- Compare answers with the reference data provided
- Generate a difference/error matrix using the results of the comparison

When you have completed this activity, you will be able to:

- Classify birds as carnivores, herbivores or omnivores using given criteria
- Compare answers to a set of validation data and produce a difference/error matrix
- Identify categories with the most errors
- Evaluate the overall accuracy of the bird classification
- Understand the importance of the Difference/Error Matrix and how to use the information it provides

Materials

1. A set of 10 bird pictures
2. Sample beak type sketches
3. Classification and Difference/Error Matrix Work Sheets for Bird Classification

What To Do and How To Do It

In the following activity you will be classifying types of birds as:

C....carnivores (meat eaters)
H...herbivores (plant eaters)
O...omnivores (plant and meat eaters)

Examples of preferred foods:

Carnivores.......fish, meat, insects, worms, small mammals
Herbivores.......vegetation, seeds, nuts, and berries
Omnivores.......all of the above

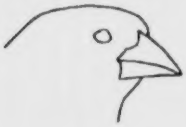
The size and shape of the bird's beak will usually indicate its preferred food type. Many birds are opportunistic, however, and will supplement their preferred diet with a variety of foods when a scarcity of food requires it.

Figure LAND-L-3: Sample Beak Types

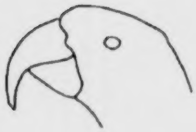
Duplicate and distribute to students.

Student Reference Sheet for Activity

Herbivore Beak Types

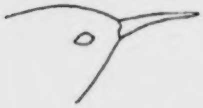


Finch Type: Heavy wedge shaped beaks are good for cracking nuts and seed

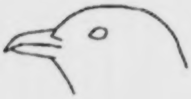


Parrot Type: Thick curved upper and lower beak are also for cracking nuts or tearing fruit apart. The upper beak as a sharp point and usually curves over the lower beak.

Carnivore Beak Types

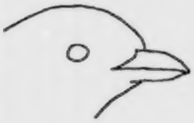


Insect Eater Type: Long slender, slightly curved beaks are used to probe for insects and spiders in tree bark and soils

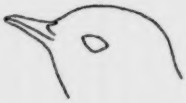


Meat Eater Type: Shorter than the insect eater, upper beak has a sharp curved overhanging tip and straight lower beak specialized for tearing meat.

Omnivore Beak Types



Jay Type: Wide, medium length beak is used for eating insects, fruit, seeds, and even carrion.



Thrush Type: Shorter and more slender than the Jay type, also for eating meat, plants, and insects.

Duplicate and distribute to students.

Bird Classification Work Sheet

Procedure

1. Look at each of the birds on the cards (numbered 1-10) and classify it as a carnivore, herbivore, or omnivore. Record each answer in the student classification column on the bird classification work sheet below.
2. Your teacher will provide the information to be recorded in the column labeled "validation data". Be sure to fill in this column accurately, this data will be needed to complete the difference/error matrix.
3. Look at all ten pairs and mark each matching pair with a check mark and each different (incorrect) pair with an "X" in the third column.

Table LAND-L-3: Bird Classification Work Sheet

Bird Id#	Student Classification	Validation Data	✔ or x
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Duplicate and distribute to students.

Difference/Error Work Sheet for Bird Classification

4. Fill in the first row of the difference/error matrix by using the following directions:
   A. Count how many times your group matched a student classification of carnivore with a validation answer of carnivore. Place that number here ______________. Now place the same number in the box labeled A1 of the difference/error matrix.
   B. Count how many times your group matched a student classification of carnivore with a validation answer of herbivore. Place that number here ______________. Now place the same number in the box labeled B1 of the difference/error matrix.
   C. Count how many times your group matched a student classification of carnivore with a validation answer of omnivore. Place that number here ______________. Now place the same number in the box labeled C1 of the difference/error matrix.

Be sure to check with your teacher before continuing...

Repeat this process for each of the other categories filling in the remaining two rows. .

Table LAND-L-4: Difference/Error Matrix for Bird Classification

Validation Data

		Carnivore	Herbivore	Omnivore	Row Total
Student Data	Carnivore	A1.	B1.	C1.	D1.
	Herbivore	A2.	B2.	C2.	D2.
	Omnivore	A3.	B3.	C3.	D3.
	Column Total	A4.	B4.	C4.	D4.

5. Sum the row totals, column totals and box D4.

Box D4 = A4 + B4 + C4 = D1 + D2 + D3
(column total) (row total)

The numbers in the outlined boxes (the major diagonal), are classified correctly. Go through the other boxes in the matrix to find any incorrect classifications. The difference/error matrix shows which categories are most difficult to identify. The numbers off the major diagonal represent "incorrect" classifications. Each error or difference is an omission from the correct category and a commission (i.e., an erroneous addition) to the incorrect category.

Which difference/error box has the largest number?

Duplicate and distribute to students.

Figure LAND-L-4: Calculating the Difference/Error Matrix

$$\text{Overall Accuracy} = \frac{(A1+B2+C3)}{D4} \times 100$$

$$\text{Overall Accuracy} = \frac{\boxed{A1} + \boxed{B2} + \boxed{C3}}{\boxed{D4}} \times 100 =$$

6. Calculate the overall accuracy as outlined on the sample work sheet.

If your answer is between:	**Your level is:**
0%-50%	Novice
51%-85%	Intermediate
86%-100%	Advanced

Follow up Discussion and Activities

1. Did you have difficulty correctly classifying a particular category. Why?
2. How could you reduce the number of errors next time?
3. What are some other ways to classify birds?
4. Do you have any suggestions for improving the classification criteria?
5. How did different students' results vary? Compare your difference/error matrix to other students' difference/error matrices to see who had the largest number of accurate answers and to see if other groups made mistakes classifying the same categories. What caused the mistakes?
6. What other measures can be used to evaluate data quality?

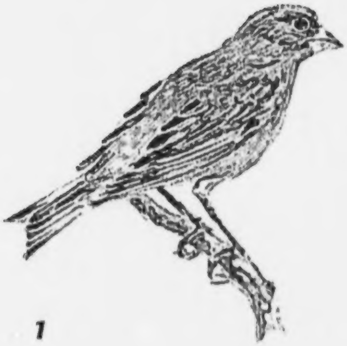
Further Investigations

1. Combine all the class data to create a class difference/error matrix. Calculate the overall accuracy of the class.
   Which do you think is more accurate, your matrix or the combined class results? Why?
2. Try to develop your own criteria for classifying a group of objects (for example, insects).

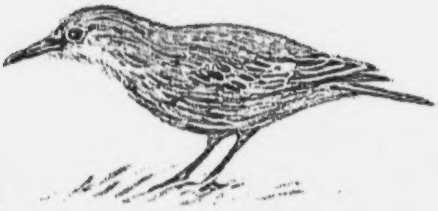
Duplicate and distribute to students.

Table LAND-L-5: Bird Classification Validation Data Sheet

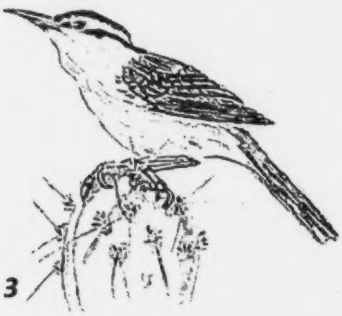
	Bird Name	Classification
1	Western Greenfinch	Herbivore
2	European Starling	Omnivore
3	Bicolored Wren	Carnivore
4	Rose-ringed Parakeet	Herbivore
5	Bru Bru Shrike	Carnivore
6	Clay Colored Robin	Omnivore
7	Pine Grosbeak	Herbivore
8	Eurasian Jay	Omnivore
9	Common Tree Creeper	Carnivore
10	Hermit Thrush	Omnivore



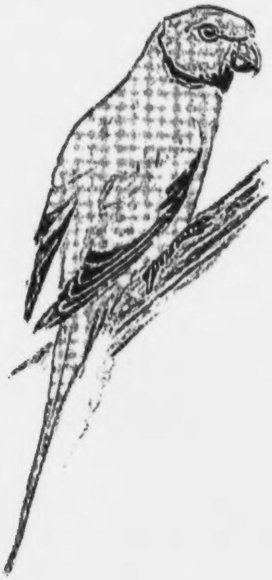
1



2



3



4

Art by Linda Isaacson

2. European Starling

(*Sturnus vulgaris*)

This bird (21 cm in size) lives in open woods, parks, and gardens in Europe and Western Asia, and has been introduced to North America, South America, Southern Australia and New Zealand. It eats both plants and animals.

Classification:

OMNIVORE

1. Western Greenfinch

(*Carduelis chloris*)

This bird (14.5 cm in size) lives in open woodland, bushes, and gardens in Europe, Northern Africa, Asia Minor, Middle East, and Central Asia. Its diet consists of nuts and seeds, especially sunflower seeds and peanuts.

Classification:

HERBIVORE

4. Rose-ringed Parakeet (*Psittacula krameri*)

This bird (41 cm in size) lives in woodlands and farmlands in Central Africa east to Uganda, India, Sri Lanka, and has been introduced to Middle and Far East, North America, England, Netherlands, Belgium, and West Germany. It eats grain or ripening fruit.

Classification:

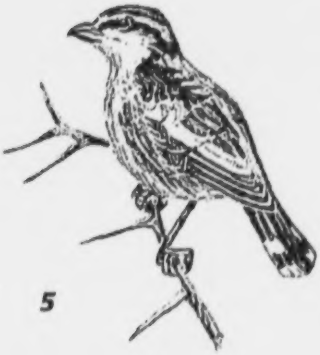
HERBIVORE

3. Bicolored Wren (*Campylorhynchus griseus*)

This bird (22 cm in size) lives in dry savanna, cactus scrub, and open woods in Colombia, Venezuela, Northern Brazil and Guyana. Its finds insects and insect eggs by peering and poking into crevices on the ground.

Classification:

CARNIVORE



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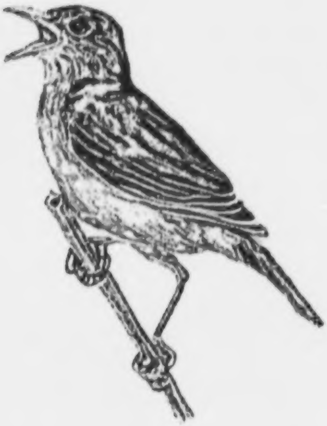

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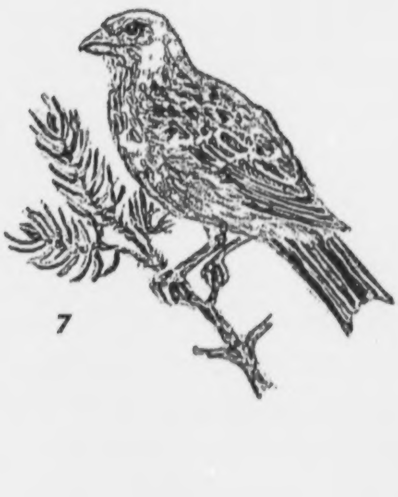

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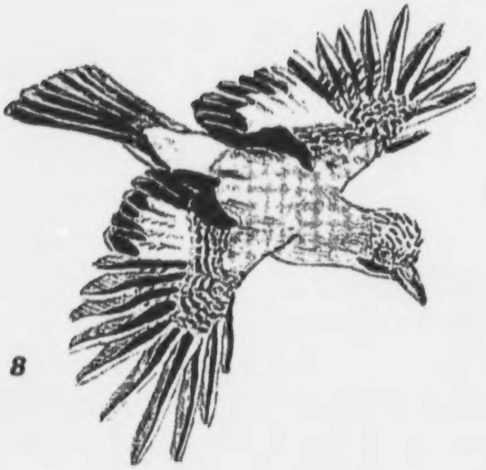


8

Art by Linda Isaacson

6. Clay Colored Robin (*Turdus grayi*)

This bird (23-24 cm in size) lives in open woodland, woodland edge and clearings, usually near streams in Southeast Mexico, Central America, coastal Colombia. It eats insects, earthworms, slugs and lizards as well as fruit.

Classification:

OMNIVORE

5. Bru Bru Shrike

(*Nilaus afer*)

This bird (15 cm in size) lives in savanna woodland and sometimes the forest edge in tropical Africa. It eats insects and catches food on the wing.

Classification:

CARNIVORE

8. Eurasian Jay

(*Garrulus glandarius*)

This bird lives in oak woods, and open country in Western Europe, across Asia to Japan and Southeast Asia. It eats insects, beech nuts and acorns.

Classification:

OMNIVORE

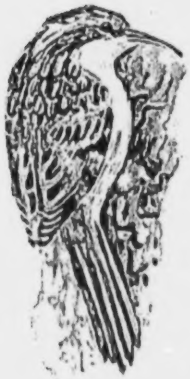
7. Pine Grosbeak

(*Pinicola enucleator*)

This bird (20 cm in size) lives in the coniferous and scrub forests of North and West North America, North Scandinavia and Siberia. It eats berries and buds on the ground or in treetops.

Classification:

HERBIVORE



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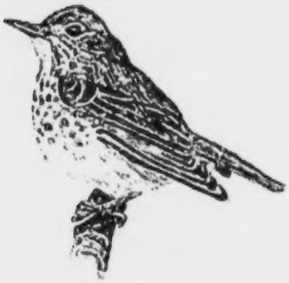


10

Art by Linda Isaacson

10. Hermit Thrush

(*Catharus guttatus*)

This bird (15-20 cm in size) lives in woodlands, forest edges and thickets in North and Central America. It eats insects, spiders, snails, earthworms and salamanders as well as fruits and seeds.

Classification:

OMNIVORE

9. Common Treecreeper

(*Certhia familiaris*)

This bird (12.5 cm in size) lives in woodlands particularly coniferous woodlands in Western Europe and Japan. It eats insects and insect eggs gleaned from tree bark.

Classification:

CARNIVORE

Reference: *The Illustrated Encyclopedia of Birds: The Definitive Reference to Birds of the World.* Consultant-in Chief Dr. C. Perrins. New York: Prentice Hall Press, 1990.

What's the Difference?

Purpose

To learn how to quantitatively evaluate the accuracy of a classification

Overview

Students will classify (sort) clouds into three possible classes: cirrus, stratus, and cumulus based on their knowledge from the *Cloud Identification Protocol*. They will then compare their answers with a given set of validation data and generate a difference/error matrix. The students will then discuss how to improve their accuracy based on identifying specific mistakes they made as indicated by the difference/error matrix.

Level

Intermediate and Advanced

Time

One class period

Key Concepts

Classification helps us organize and understand the natural world.

In order for classification systems to be useful, we need to quantitatively determine their accuracy.

Criteria are used to define accuracy levels.

Skills

Classifying clouds

Evaluating the accuracy of the classification

Improving the accuracy of the classification based on the evaluation

Analyzing data to understand the interrelationships of a classification and its accuracy

Identifying decision criteria for a classification system

Collecting and *interpreting* validation data

Building and *analyzing* a difference/error matrix for accuracy assessment

Solving problems cooperatively to resolve accuracy issues

Materials and Tools

Sets of laminated cloud pictures

Answer key (validation data sheet)

Procedures for this activity

Classification Work Sheet

Difference/error Matrix Work Sheet.

Preparation

The student work sheets need to be reproduced for each group.

Prerequisites

An activity covering the basics of classification, experience with the GLOBE *Cloud Identification Protocol*, and the *How Accurate Is it? Introducing the Difference/Error Matrix Learning Activity*

Background

Scientists classify many features of our environment, such as species of life, forest types, or soil types. While these classifications are really arbitrary human impositions on the natural world, they are also a fundamental mechanism for helping us to organize and to understand the natural world. There may be several different appropriate ways to classify a set of objects of interest. Two particular objects may be classified differently either because of error on the part of one or both of the classifiers, or simply because different classifying criteria were used. In any case, we need to know how much error is in our classification in order to use the information we have obtained with some confidence in its accuracy. Ultimately, the information generated by the classification of remotely sensed data will be used to make important decisions about global problems such as deforestation, global warming, and environmental degradation. It is imperative that we not make these decisions based on information that is inaccurate.

A difference/error matrix is the basic tool used for accuracy assessment of remotely sensed data. Its value is that it not only gives us a mechanism for generating a numerical rating of the overall accuracy of a classification or map, but it also provides a tremendous amount of information about the sources of error. This can focus our attention on those areas or classes that require it. We can use this information to improve the quality of our classification criteria, and to improve our skill at distinguishing those classes for which there is a lot of confusion. The use of cloud classification as the basis for this activity will both build upon and strengthen students' cloud identification skills from the GLOBE climate protocol.

Key Terms and Concepts

See Key Terms and Concepts under *How Accurate Is It? Introducing the Difference/Error Matrix* .

Acknowledgment

Art by Linda Isaacson.

References

National Audubon Society Pocket Guide to Clouds and Storms. New York: Alfred A. Knopf, Inc, 1995

GLOBE Cloud Chart, 1996

You may want to make an overhead of the next page with the example Cloud Classification Work Sheet and Difference/Error Matrix. The instructions are on this page.

Tallying Procedure and Overall Accuracy Calculation

For the following procedures refer to the sheet marked "example":

Step 1 For sample number 1 from the Cloud Classification Work Sheet (Table 21) determine the Student Classification cloud type (Table 21, cell A - Cirrus).

Step 2: In Table 22, the Difference/Error Matrix, find the matching student classification cloud type (cirrus) in the left-hand column.

Step 3: For sample number 1 from the Cloud Classification Work Sheet (Table 21), determine the Validation Data cloud type (Table 22, cell B - Stratus).

Step 4: In Table 22, the Difference/Error Matrix, from the cell with the identified Student Classification cloud type (cirrus), move along the row (left-to-right) until you find the category along top row which matches the Validation Data cloud type (Stratus). In the cell at the intersection between the cirrus row and the Stratus column (cell B3), tally one and move to the next sample. In this way, the rows represent the student data, and the columns represent the validation data.

Step 5: Move to sample 2 in the Cloud Classification Work Sheet and continue this process. After you have completed tallying all of the samples, you must calculate the overall accuracy.

Step 6: The total number of samples (cell D4) equals the row total (D1 + D2 + D3), which also equals the column total (A4 + B4 + C4). The total correct classifications equals the sum of the cells A1 + B2 + C3 (the major diagonal, bold-bordered cells). Divide the total correct, 1, by the total number of samples, 3. Multiply by 100 to get a percentage - 33%. This value represents the overall accuracy of the student classification.

Step 7: Just as the cells along the major diagonal represent all the "correct" classifications, the cells which are off the major diagonal represent "incorrect" classifications or differences. Hence the name difference matrix or error matrix. Each error or difference is also an *omission* from the MUC class in which it should have been classified, and a *commission* (i.e., erroneous addition) to the incorrect MUC class. This information can be used to identify cloud types that were particularly difficult to classify, and also which cloud types were confused with each other.

Table LAND-L-6: Example Cloud Classification Work Sheet

Sample Number	Photo Number	Student Classification	Validation Data	✔	X
1	3a	A: Cirrus	B: Stratus		X
2	3c	C: Stratus	D: Stratus	✔	
3	3d	E: Stratus	F: Cumulus		X

(See Validation Key, Table _______; and Figure ______:Cloud Classification Samples.)

Table LAND-L-7: Cloud Classification Difference/Error Matrix Example

		Cumulus	Stratus	Cirrus	Row Total
Student Data	Cumulus	A1:	B1:	C1:	D2: 0
	Stratus	A2: 1	B2: 1	C2:	D2: 2
	Cirrus	A3:	B3: 1	C3:	D3: 1
	Column Total	A4: 1	B4: 2	C4: 0	D4: 3

Validation Data

$$\mathbf{D4} = \underset{\text{(column total)}}{\mathbf{A4 + B4 + C4}} = \underset{\text{(row total)}}{\mathbf{D1 + D2 + D3}}$$

$$\text{OVERALL ACCURACY} = \frac{\text{A1} + \text{B2} + \text{C3}}{\text{D4}} \times 100 = (1/3) \times 100 = 33\%$$

What To Do and How To Do It

1. To prepare your students, discuss with them the following questions:
    - What is the difference/error between a classification category an a classification criteria?
    - Why is classification an important activity?
    - How does classification relate to mapping?
    - Why is it important for a map to be accurate?
2. Copy and distribute the student instructions, and the numbered cloud photos.
3. Have your students follow the instructions on the work sheets to do the following steps:
    - classify the clouds into categorized by type of cloud.
    - cross reference with the validation cloud types.
    - prepare the Difference/Error Matrix.
4. Discuss with your students how this activity relates to the *Accuracy Assessment Protocol*.

Duplicate and distribute to students.

Student Materials

Overview

Scientists classify many features in our environment such as species of life, forest types, or rock types. These classifications, or categories, help us to organize and understand the natural world. In order for these classifications to be useful for scientists, we need to know how accurate they are. A difference/error matrix is the basic tool used to measure the accuracy of a classification procedure. This difference/error matrix also shows us where there was confusion, or difficulty classifying certain classes.

In this activity, images of clouds will be classified into 3 clearly defined categories according to given criteria. Results of this classification will be compared with validation (reference) data by entry onto a chart. The accuracy of charted results will be tallied in a difference/error matrix.

When you have completed this activity, you will be able to:

- classify a set of items (images of clouds) into a well-defined classification scheme
- compare the classifications to a set of validation data to generate a difference/error matrix
- gain an understanding of the meaning of measurement accuracy and precision
- gain insight into some sources of error in scientific measurements.

Materials and Tools

A set of 20 cloud pictures
Copy of procedure with cloud type sketches and Difference/Error Matrix
Cloud Classification Work Sheet

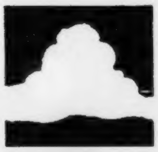
What To Do and How To Do It

1. Carefully spread out the numbered cloud photos as provided and directed by your teacher. Twenty (20) will be classified in this exercise.
2. Using a Cloud Classification Work Sheet, classify all of the clouds in the dataset into three categories: cumulus, stratus, and cirrus.

   Note: Cloud types do not always fit exactly into in these three basic categories. For the purpose of this exercise, use only this simplified classification scheme. Some confusion may occur in the classification process. Accept this 'fuzziness' as part of the uncertainty in the activity. This uncertainty is part of the nature of science, any particular classification scheme never exactly matches the perceived state of the natural world.

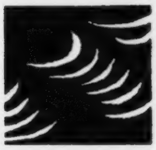
Duplicate and distribute to students.

The criteria for the classes are as follows:



cumulus: detached clouds, generally dense and with sharp outlines, developing vertically in the form of rising mounds, domes or towers, of which the upper bulging part often resembles a cauliflower;

stratus: generally gray cloud layer with a fairly uniform base;



cirrus: detached clouds in the form of white, delicate filaments or white or mostly white patches or narrow bands. These clouds may look like horsetails.

3. Sort the clouds into three piles or columns (cumulus, stratus, and cirrus), leaving photos which are difficult to classify between the piles or columns. After classifying all the photos, return to the photos which were difficult to classify. Make a final determination of the appropriate class for each of these. If there is more than one type of cloud in a photo, you must select one dominant cloud type to classify the photo. The decision criteria for the dominant cloud type is whichever cloud type covers the greatest percentage of the sky in the photo. Check your classifications for each one of the twenty photos and record these in the Student Classification column on the Cloud Classification Work Sheet.
4. Your teacher will provide the validation cloud types to the class. You must record the validation cloud type for each photo in the Validation Data column on the Cloud Classification Work Sheet. A record of all the validation cloud types will be *necessary* to complete the exercise!
5. For each photo in which the Student Classification cloud type matches the Validation Data cloud type, put a check (+) in the (X or +) column. For each photo which does not match, put an X in the (X or +) column.

Duplicate and distribute to students.

6. Tally the results from the match (X or +) column in the matrix using the following directions and the example:
   - A. Using the Cloud Classification Work Sheet, count how many times your group matched a student classification of cumulus with a validation answer of cumulus. Place that number here __________. Now place the same answer in cell A1 in the Difference/Error Matrix below.
   - B. Now count how many times your group matched a student classification of cumulus with a validation answer of stratus. Place that number here _______. Now place the answer in cell B1 below.
   - C. Check with your teacher before going further!
   - D. Fill in the rest of the Difference/Error Matrix following the same procedure.
   - E. Double-check that every sample from the Cloud Classification Work Sheet has been tallied in the Difference/Error Matrix. Now, calculate the overall accuracy of your classification according to the formula at the bottom of this page.

Table LAND-L-8: Cloud Classification - Difference/Error Matrix Work Sheet

		Validation Data			
		Cumulus	Stratus	Cirrus	Row Total
Student Data	Cumulus	A1:	B1:	C1:	D2:
	Stratus	A2:	B2:	C2:	D2:
	Cirrus	A3:	B3:	C3:	D3:
	Column Total	A4:	B4:	C4:	D4:

$$\mathbf{D4} = \mathbf{A4 + B4 + C4} = \mathbf{D1 + D2 + D3}$$

$$\text{(column total)} = \text{(row total)}$$

$$\text{Overall accuracy} = \frac{A1 + B2 + C3}{D4} \times 100$$

Overall accuracy = ______________________ x 100 =_________

Table LAND-L-9: Cloud Classification W ork Sheet

Sample Number	Photo Number	Student Classification	Validation Data	✔	X
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Table LAND-L-10: Cloud Classification - Validation Data Sheet

(Answer Key)

Photo #	Validation Data
1	Cirrocumulus
2	Cirrostratus
3	Cumulus
4	Stratus
5	Cirrus
6	Stratocumulus
7	Altocumulus
8	Altostratus
9	Nimbostratus
10	Cumulonimbus
11	Nimbostratus
12	Cumulonimbus
13	Altocumulus
14	Cirrostratus
15	Cirrostratus
16	Altocumulus
17	Nimbostratus
18	Cumulus
19	Altocumulus
20	Nimbostratus

Student accuracy measure:	**Level:**
0%-50%	Novice
51%75%	Intermediate
76%-100%	Advanced

Figure LAND-L-5 (photo 1)

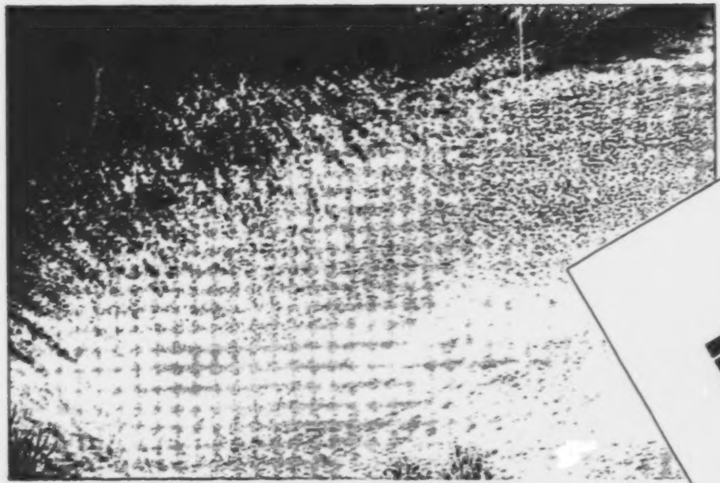
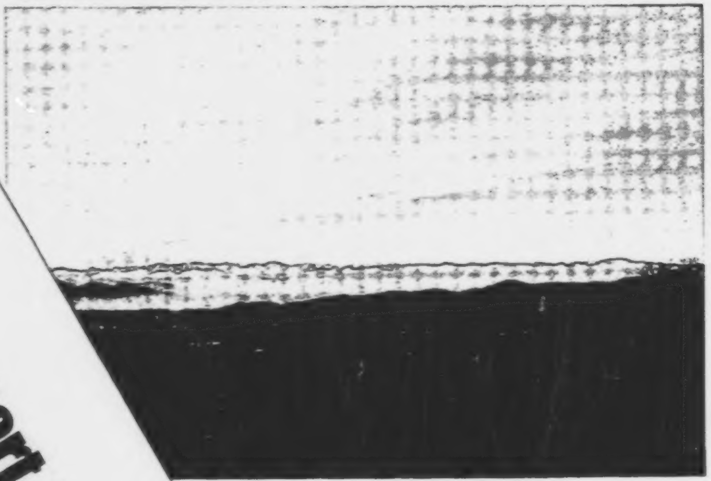
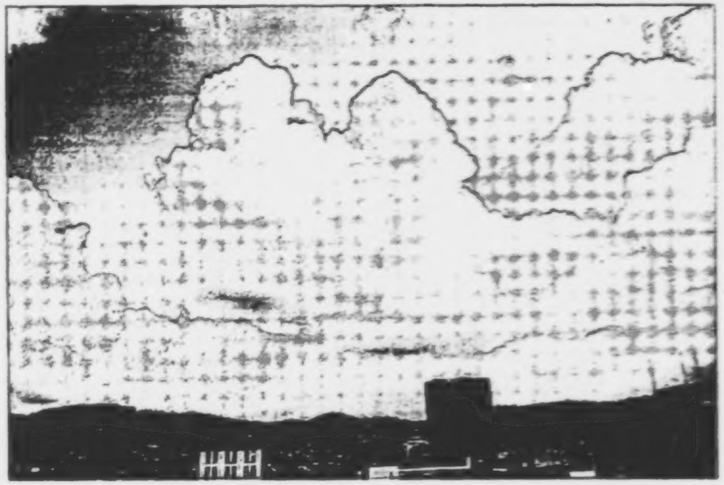


Figure LAND-L-6 (photo 2)

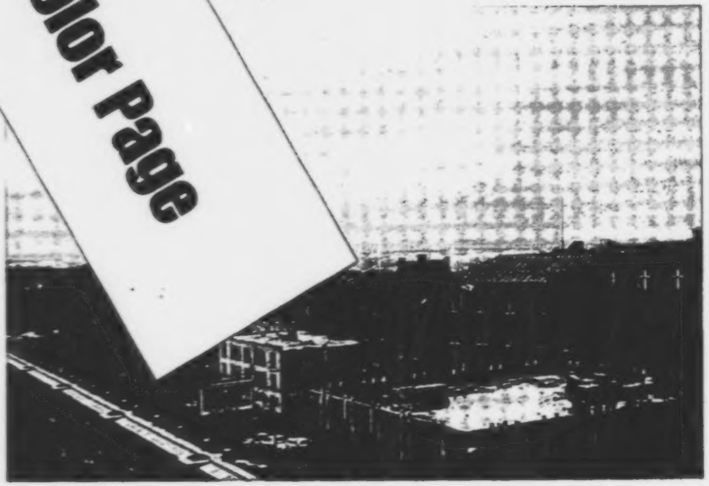


Insert Color Page

Figure LAND-L-7 (photo 3)



hoto 4)



Source: Wayne M. Faas and Grant Goodge of the National Climatic Data Center, NOAA

Figure LAND-L-5 (photo 1)
Cirrocumulus: high clouds with puffy, patchy appearance, with small spaces between clouds. Often form wave-like patterns.

Figure LAND-L-6 (photo 2)
Cirrostratus: high clouds, light gray or white, often thin with the sun or moon seen through them. Usually covers much of the sky.

Figure LAND-L-7 (photo 3)
Cumulus: low clouds. Clouds appear puffy, and look like cotton balls, popcorn or cauliflower.

Figure LAND-L-8 (photo 4)
Stratus: low clouds, light or dark gray and generally uniform in appearance and cover most of the sky. Fog is a stratus cloud.

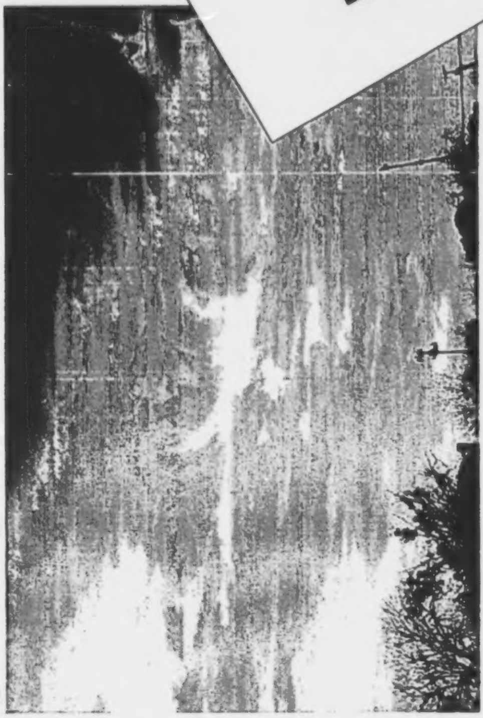


Figure LAND-L-9 (photo 5)

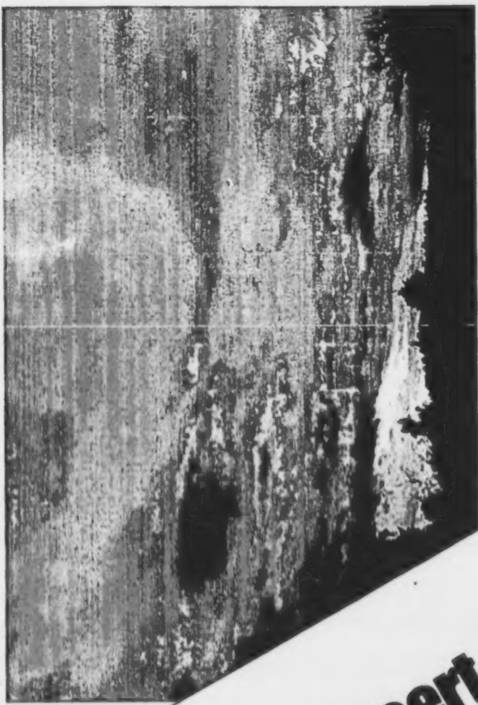


Figure LAND-L-10 (photo 6)

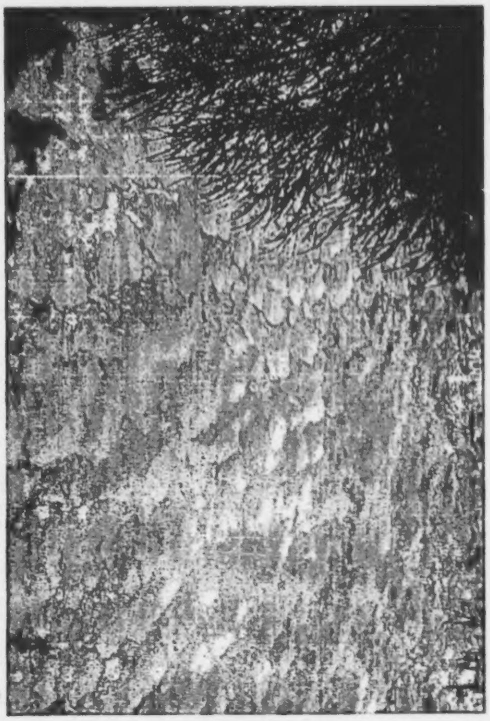
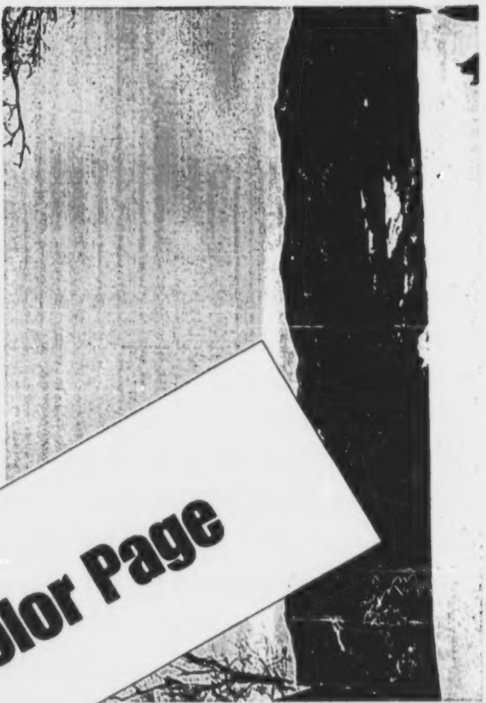


Figure LAND-L-11 (photo 7)



hoto 8)

Insert Color Page

Source: Wayne M. Faas and Grant Goodge of the National Climatic Data Center, NOAA

Figure LAND-L-9 (photo 5)
Cirrus: high clouds, thin wispy and feathery, composed of ice crystals.

Figure LAND-L-10 (photo 6)
Stratocumulus: low clouds, with irregular masses of clouds, rolling or puffy in appearance, sometimes with space between the clouds.

Figure LAND-L-11 (photo 7)
Altocumulus: middle clouds with puffy, patchy appearance, usually with spaces between clouds.

Figure LAND-L-12 (photo 8)
Altostratus: middle clouds, light gray and uniform in appearance, generally covering most of the sky.

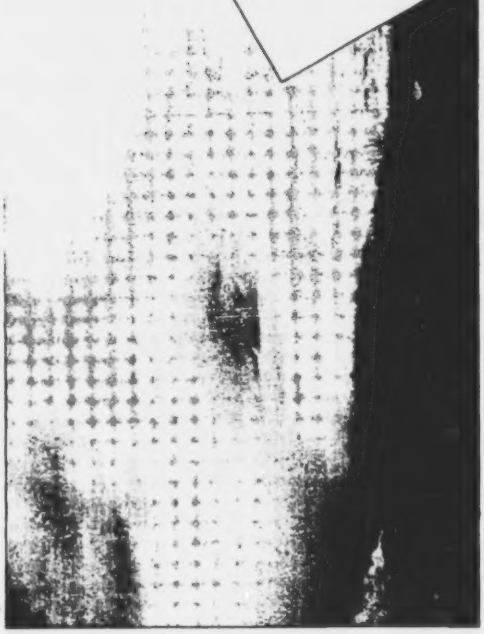


Figure LAND-L-13 (photo 9)

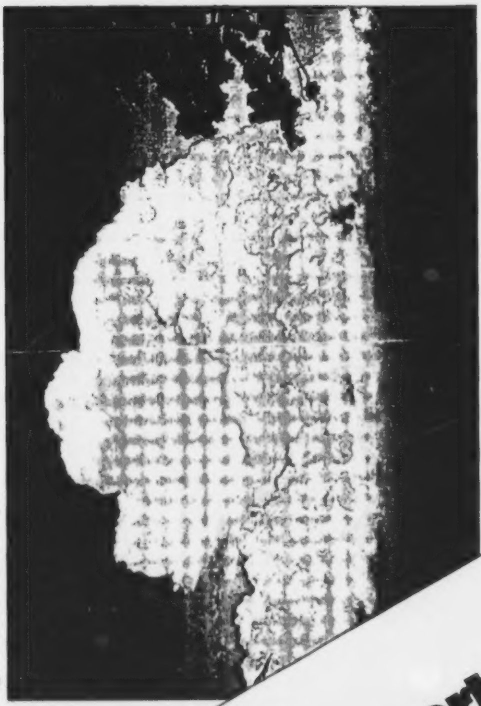


Figure LAND-L-14 (photo 10)

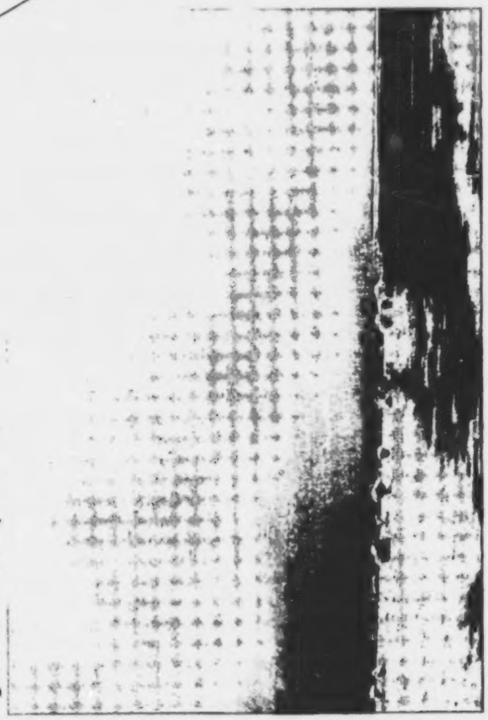


Figure LAND-L-15 (photo 11)

(photo 12)

Insert Color Page

Source: Wayne M. Faas and Grant Goodge of the National Climatic Data Center, NOAA

Figure LAND-L-13 (photo 9)

Nimbostratus: low and middle dark gray clouds with precipitation falling from them. Bases are diffuse and difficult to determine because of falling precipitation.

Figure LAND-L-14 (photo 10)

Cumulonimbus: large clouds with dark bases and tall billowing towers. Can have sharp well defined edges or anvil shape at the top. Precipitation can obscure the base of the clouds. Can be accompanied by thunder.

Figure LAND-L-15 (photo 11)

Nimbostratus: low and middle dark gray clouds with precipitation falling from them. Bases are diffuse and difficult to determine because of falling precipitation.

Figure LAND-L-16 (photo 12)

Cumulonimbus: large clouds with dark bases and tall billowing towers. Can have sharp well defined edges or anvil shape at the top. Precipitation can obscure the base of the clouds. Can be accompanied by thunder.

Figure LAND-L-17 (photo 13)

Figure LAND-L-18 (photo 14)

Insert Color Page

Figure LAND-L-19 (photo 15)

to 16)

Source: Wayne M. Faas and Grant Goodge of the National Climatic Data Center, NOAA

Figure LAND-L-17 (photo 13)

Altocumulus: *middle clouds with puffy, patchy appearance, usually with spaces between clouds.*

Figure LAND-L-18 (photo 14)

Cirrostratus: *high clouds, light gray or white, often thin with the sun or moon seen through them. Usually covers much of the sky.*

Figure LAND-L-19 (photo 15)

Cirrostratus: *high clouds, light gray or white, often thin with the sun or moon seen through them. Usually covers much of the sky.*

Figure LAND-L-20 (photo 16)

Altocumulus: *middle clouds with puffy, patchy appearance, usually with spaces between clouds.*

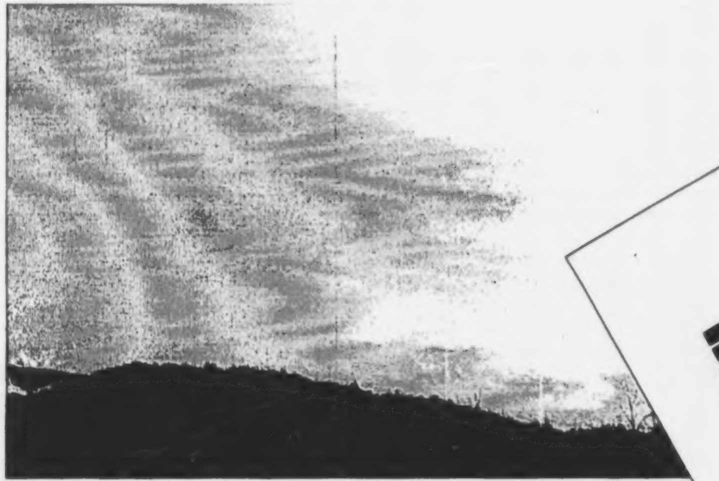


Figure LAND-L-21 (photo 17)

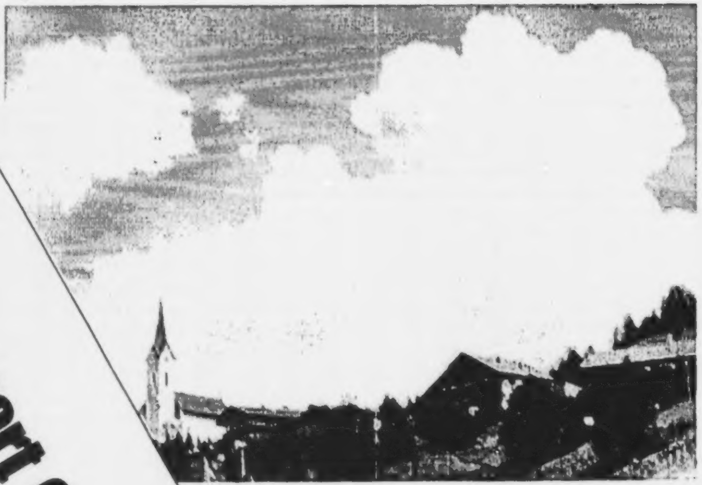


Figure LAND-L-22 (photo 18)

Insert Color Page

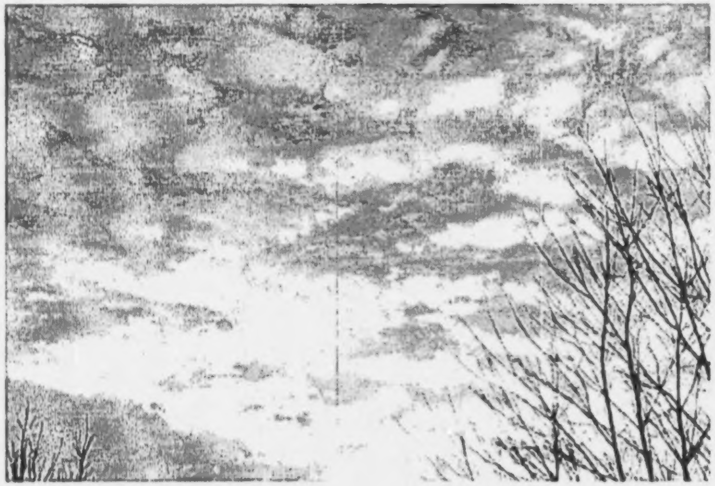
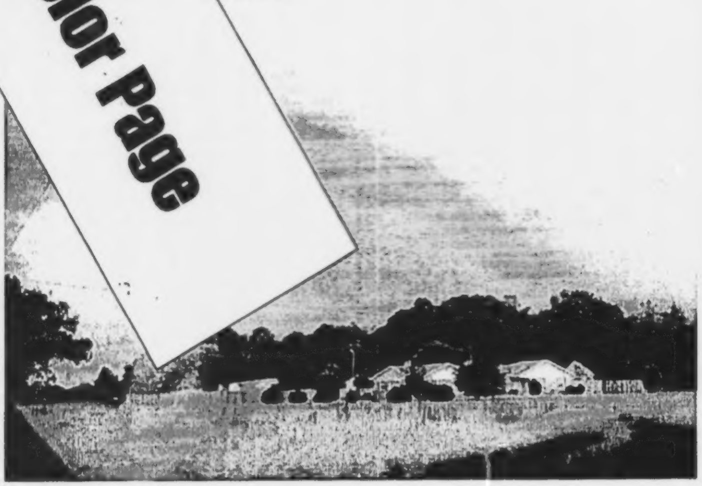


Figure LAND-L-23 (photo 19)



hoto 20)

Source: Wayne M. Faas and Grant Goodge of the National Climatic Data Center, NOAA

Figure LAND-L-21 (photo 17)

Nimbostratus: low and middle dark gray clouds with precipitation falling from them. Bases are diffuse and difficult to determine because of falling precipitation.

Figure LAND-L-22 (photo 18)

Cumulus: low clouds. Clouds appear puffy, and look like cotton balls, popcorn or cauliflower.

Figure LAND-L-23 (photo 19)

Altocumulus: middle clouds with puffy, patchy appearance, usually with spaces between clouds.

Figure LAND-L-24 (photo 20)

Nimbostratus: low and middle dark gray clouds with precipitation falling from them. Bases are diffuse and difficult to determine because of falling precipitation.

Odyssey of the Eyes

Beginning Level

Purpose

To familiarize students with the concept of modeling as it is related to remote sensing

Overview

In *Odyssey of the Eyes*, students will create a 3-D model of an area and develop a classification system for the land forms in their model. They will use their eyes as remote sensors and view the model from a variety of heights. The eyes will journey from very close to as far away as a satellite. Each time the student will create a map of the image they see. The maps can then be used to answer certain questions about the environment.

Time

Three to four class periods

Level

Beginning

Key Concepts

- A map is a symbolic representation of a certain land area.
- The field of view is how large an area your eye or a camera's eye can perceive.
- The field of view increases the higher the eye is relative to the ground.

Skills

- *Modeling* a landscape
- *Drawing* the landscape from various perspectives

Materials and Tools

- Paper towel or toilet paper tubes
- A variety of objects to make the models (either teacher or student supplied).
- Glue
- Tape
- Ruler

Preparation

Gather all materials prior to the building of the model.

Prerequisites

The students should be briefed on some very basic components about maps and models such as map keys and symbols.

Note: This activity presents concepts similar to those in steps 8, 9, and 10 of the *Relative and Absolute Directions Learning Activity* in the *GPS Investigation.*

Background

Maps are the most common model to represent the Earths' surface. The concepts of mapping and modeling are important in order for students' to understand the remote sensing protocols. For example, the satellite images that the students will view during the protocols are models of the Earth taken from satellites.

As a satellite revolves around the Earth, it takes pictures with a sensor that is sensitive to a variety of different wavelengths. One of the main wavelengths sensed is thermal radiation. The sensor reads the amount of heat being radiated and makes a picture out of the different values. In this activity students themselves will be acting as remote sensors of thermal radiation.

Although students may not know it, they have a great deal of experience with remote sensing. Anytime they observe something without touching it they are actually using their eyes, ears, nose, and skin surface to remotely sense that object. We may think of remote sensing as work that is only done by satellites, yet there are many instruments that are used to remotely sense objects. Your students may have experience in photography or in using a microscope. Both of these instruments give us information that we would not be able to access if we attempted to observe an object with our own, limited, senses.

The satellite images students will use in the protocols are made up of tiny squares, each square contains information about a certain land cover area. We call these photos digital. The tiny squares seen on these pictures are called pixels. Some images have pixels that represent a large area on the ground and others have pixels that represent smaller areas.

Scientists who study land cover use a variety of aerial photography and satellite images dependent on the purpose of their study. The GLOBE scientists are interested in analyzing the satellite photos to determine land cover types and land use changes over time.

In the remote sensing protocol, we are creating a thematic map of a 15 km x 15 km area with your school near the center. The information on the image you receive has been accumulated from a satellite. Your students will be classifying the land cover types with the use of the computer and also conducting ground verification of the resulting image. It is important for them to understand the concepts of modeling and remote sensing if they are to have a clear understanding of where this information comes from and the significance of it.

Resources: (Optional)

Looking Down, Jenkins, Steve, Hutton Houghton Mifflin, NY, 1995, 0-395-72665-4

View from the Air, Lindberg, R., Viking, NY, 1995, 0-670-84660-0

Mouse Views, McMillan, B., Holiday House, NY, 1995, 0-8234-1132-x

What To Do and How To Do It

Part 1: Building and Viewing the Model

1. Students form groups and write a plan for building a model of an area, real or imagined. The school yard is a popular choice, however, the design of the model should be student generated. Students should list materials necessary and draw a proposed picture of their model. See Odyssey of the Eye's registration form found after *Odyssey of the Eyes: Advanced Level.*
2. Students will need two to three class periods to build their models.
3. Students will now use their eyes to view the model through a paper towel tube from four different views. This will give students an opportunity to view a change in resolution and a change in field of view. Have students record their observations on Odyssey of the Eyes Observation Form found after *Odyssey of the Eyes: Advanced Level.*
   a. Mouse View — Observe the model from the side. Draw and label the map.
   b. Bee's View — Observe from 10 cm above the model. Draw and label the map.
   c. Bird's Eye View — Observe from desk level. Draw and label the map.
   d. Satellite View — Observe from a second story window or stairwell. Draw and label the map.

Discussion questions

1. Are there any visual differences between the Bee's View and the Mouse's View? What are they?
   Note: Young elementary school children often have more difficulty with the concept of "top view." Some extra time may be needed here. See resource list for suggested resources.
2. Compare your four drawings. Which view would be the most useful if you were:
   a. An eagle looking for a mouse?
   b. Deciding where to build a mall?
   c. Looking for animal tracks?

   d. Studying the extent of deforestation or reforestation?
   e. Finding a lost child in the woods?
   f. Seeing how much of the forests of your area have been damaged by pollution?
   g. Looking for a lost pin?
3. What are the advantages of using satellites to view the Earth? Are there any disadvantages?

Part 2: Making a symbolic map of the model

1. For each land cover item in the model (roads, rocks, playground equipment, pond, river, grass, houses, etc.), have students pick a symbol to represent it. List the land cover items with their symbol in the Odyssey of the Eyes Symbolic Map Data Sheet found after *Odyssey of the Eyes: Advanced Level.*
2. Use the symbols to create a map of this area. Draw the map on the Symbolic Map Data Sheet found after *Odyssey of the Eyes: Advanced Level.*
3. Student groups exchange symbolic maps, decipher the maps, and write a fictional story about an event that could occur within the depicted environment.

Discussion questions

1. If you were asked to make a map of your neighborhood would you prefer to draw a true to life map or a map using symbols? Support your answer.
2. Research map types and the purpose for each map type.

Odyssey of the Eyes
Intermediate Level

Purpose

To familiarize students with the concept of modeling as it is related to remote sensing and to introduce students to the process of digitizing pictures similar to the ones produced by a satellite's remote sensing equipment

Overview

In this intermediate level activity, *Odyssey of The Eyes* students will use the symbolic map created in the beginning activity to produce a digitized photo similar to the ones produced by a satellite's remote sensing equipment. As they perform the activity they will begin to see why ground verification of satellite data is necessary in order for scientists to create accurate models of the Earth's systems.

Time

Three to four class periods

Level

Intermediate

Key Concepts

- Objects in a remotely sensed image are interpreted and digitized into a code based upon the object's reflectance of bands of light.
- The image codes are relayed through a satellite dish to a computer for storage or enhancement.
- Image display is accomplished by conversion of stored data to a user-defined color-coded image.

Skills

- *Observing* an image
- *Interpreting* an image
- *Classifying* an image
- *Digitizing* an image
- *Coloring* an image

Note: This activity presents concepts similar to those in steps 8, 9, and 10 of the *Relative and Absolute Directions Learning Activity* in the *GPS Investigation*.

Materials and Tools

- Graph paper
- Pencils
- Plastic overlay with grid
- Image of the Panda Bear
- Colored pencils

Preparation

Assemble the materials.

Demonstrate the process of digitizing to the class before you have students work with partners.

Prerequisites

Students should be briefed on the process by which satellites receive their information and relay it to computer.

The beginning activity is necessary for the completion of this activity.

What To Do and How To Do It

Part 1: How Digitized Pictures Are Made

Students will learn how satellites and computers communicate with each other. One student will serve as the satellite and the other will represent the computer. Using a black and white image, the satellite will scan the image translating it into a digitized code. The computer will translate the numeric code reproducing the image.

1. Students work in pairs. One serves as the satellite and the other represents the computer. The satellite places the plastic overlay over the black and white of the Panda Bear and scans the image one box at a time, starting at the left hand corner of the image. The satellite calls out a number code for each box to the computer.
2. The satellite will interpret each square according to the following guidelines:
   - If a box is white the satellite interprets the message as a "1" and the computer writes that number in the code.
   - If a box is black the satellite interprets the message as a "2" and the computer writes that number in the code.
   - If a box is neither all black nor all white the satellite must make a decision as to the best possible choice, "1" or "2". The satellite communicates that number to the computer and the computer writes it down in the code.
   - The satellite indicates the beginning and end of each scan line with a "0".
3. Using a pencil, the student representing the computer translates the digital code onto the graph paper creating a satellite image.

   Note: See the digital code in the advanced level of this activity for an example. Additional practice can be had using student generated color pictures and different size grids.

Part 2: Making a Digitized Map

1. Supply each group with a plastic grid overlay. Have the students place this grid over their symbolic map from the beginning activity. They will now have to create a color and number code for the land cover items. They are to place the data on the Odyssey of the Eyes Digitized Data Sheet (found after *Odyssey of the Eyes: Advanced Level*).
2. Assign each land form on the symbolic map a color and a number. Record this on the Digitized Data Sheet.

Ex.	buildings	1	blue
	trees	2	green

3. Scan each line of the symbolic map matching each square with a number. Record the numbers on the data chart. Begin and end each scan line with a "0". Review the guidelines in part one of this activity for further assistance. You have created a digital code for your symbolic map.
4. Using the digitized code, select the matching colors and reproduce the map as a digitized image on a piece of graph paper.

Discussion Questions

1. How different are the proportions of land cover types as compared to their symbolic map?
2. How different are the proportions of land cover types as compared to their original model?
3. Compare and contrast maps produced by different groups:

   How do you know the maps are accurate?

   What happens to land cover types that are small in area when you draw a symbolic map or digitize an image?

   How do these changes affect what type and amount of land cover you see?

Note: Ground verification is what you are doing in some of the protocols. It is checking what is actually on the ground compared to what is represented by a satellite image or a model.

Odyssey of the Eyes
Advanced Level

Overall Purpose

To familiarize students with the concept of modeling as it is related to remote sensing

Advanced Level Purpose

In this advanced level activity, students exchange the digitized versions of their map with students in another school or classroom. Each group of students recreates the original image's cover types.

Overview

The advanced level of *Odyssey of the Eyes* demonstrates how a satellite sensor relates information to the computer. The students translate their maps into digital code and send it to another class room for translation into a color map. The connection between remote sensing technology, computer imagery and land cover assessment should be solidified at this point.

Time

Three to four class periods

Level

Advanced

Key Concepts

- Objects in a remotely sensed image is interpreted and digitized based upon the object's reflectance of bands of light.
- The image codes are relayed through a satellite dish to a computer for storage or enhancement.
- Image display is accomplished by conversion of stored data to a user-defined color-coded image.

Skills

Observing an image
Interpreting an image
Classifying an image
Interpreting color codes for an image

Note: This activity presents concepts similar to those in steps 8, 9, and 10 of the *Relative and Absolute Directions Learning Activity* in the *GPS Investigation.*

Materials and Tools

- Internet (optional)
- Graph paper
- Colored pencils
- Digitized map produced from Part 2 of *Odyssey of the Eyes: Intermediate Level*
- Computer Skills

Preparation

Assemble the materials.

Students will exchange digitized versions of their map with students in another school or classroom so a classroom or a school needs to be contacted in advance.

Prerequisites

Students should be briefed on the process by which satellites receive their information and relay it to computer.

The beginning level activity is necessary for the completion of this activity.

The students need to complete the Intermediate level activity.

What To Do and How To Do It

1. In the previous activity *Odyssey of the Eyes: Intermediate Level*, your students translated their map models into a digitized code. Type this digitized code into a word processor. Use a "0" to begin and end each line of the map. Allow the numbers to "word wrap" on the screen so that the map pattern is not visible in the message.

   example:

   011112200111133002464340024644400255655004444444001111220011113300111133001
   111122001111330011113300246434002464440025565500444444400111122001111330024643
   40024644400255655002464340024644400255655004444444001111220025565500444444400 11
   1122001111330011113300111122001111330011113300246434002464440025565500444444400111122

2. Include the key to translate from codes to colors. (See Odyssey of the Eyes Digitized Data Sheet as filled in during the Intermediate Level activity.)

   Example:

   1 violet

   2 indigo

   3 green

   4 yellow

   5 orange

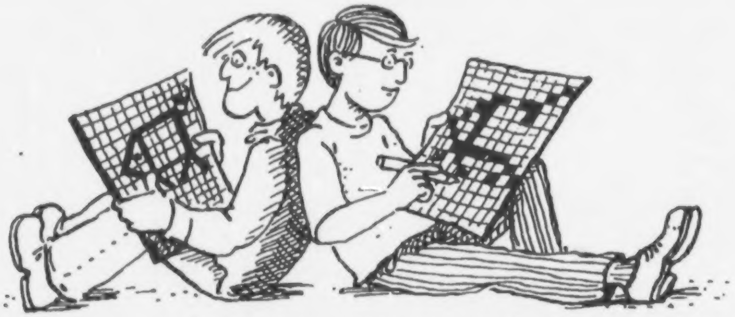
   6 red

3. Students in another class or school will receive the code and translate the code into a color map, producing a false color image. The completed maps can be returned to the sending school for verification.

Note: This exchange can be done on the Internet, by exchanging disks between schools or classes, or just by exchanging hard copies of the information.

Discussion Questions

1. What is the most dominant land covers on your false color image? To what geographical region do you think this area would belong?
2. Can you recreate a sketch of a map or a model of the area?



Source: Jan Smolík, 1996, TEREZA, Association for Environmental Education, Czech Republic

Table LAND L-11: Registration Form - Odyssey of the Eyes

Odyssey of the Eyes
Names of Group Members:
Date:

Registration Form

Description and Diagram of Proposed Model

Materials Needed:	Provided By:

Figure LAND-L-25: Observation of the Model - Odyssey of the Eyes

Odyssey of the Eyes

Observations of the Model

NAME:

DATE:

Airplane View

Satellite's View

Figure LAND-L-26: Observations of the Model - Odyssey of the Eyes

Odyssey of the Eyes

Observations of the Model

NAME:

DATE:

Bee's Eye View

Bird's Eye View

Table LAND-L-12: Symbolic Map Data Sheet - Odyssey of the Eyes

Odyssey of the Eyes

NAME:

DATE:

Symbolic Map Data Sheet

LAND COVER KEY

Land cover item	Symbol
Road	Checked areas
Trees	Squares

1.
2.
3.
4.
5.
6.
7.

SYMBOLIC MAP

Including dimensions of model in centimeters (Length and width)

Table LAND-L-13: Digitized Data Sheet - Odyssey of the Eyes

Odyssey of the Eyes

NAME:

DATE:

Digitized Data Sheet

Color and Number Code Key

Land cover	Symbol	Number	Digitizing Color

Digitized Code

Use a 0 to indicate the beginning and ending of each scan line.

0____ ____ ____ ____ ____ ____ ____ ____0
0____ ____ ____ ____ ____ ____ ____ ____0
0____ ____ ____ ____ ____ ____ ____ ____0
0____ ____ ____ ____ ____ ____ ____ ____0
0____ ____ ____ ____ ____ ____ ____ ____0
0____ ____ ____ ____ ____ ____ ____ ____0
0____ ____ ____ ____ ____ ____ ____ ____0
0____ ____ ____ ____ ____ ____ ____ ____0
0____ ____ ____ ____ ____ ____ ____ ____0

Figure LAND-L-27: Grid - Odyssey of the Eyes

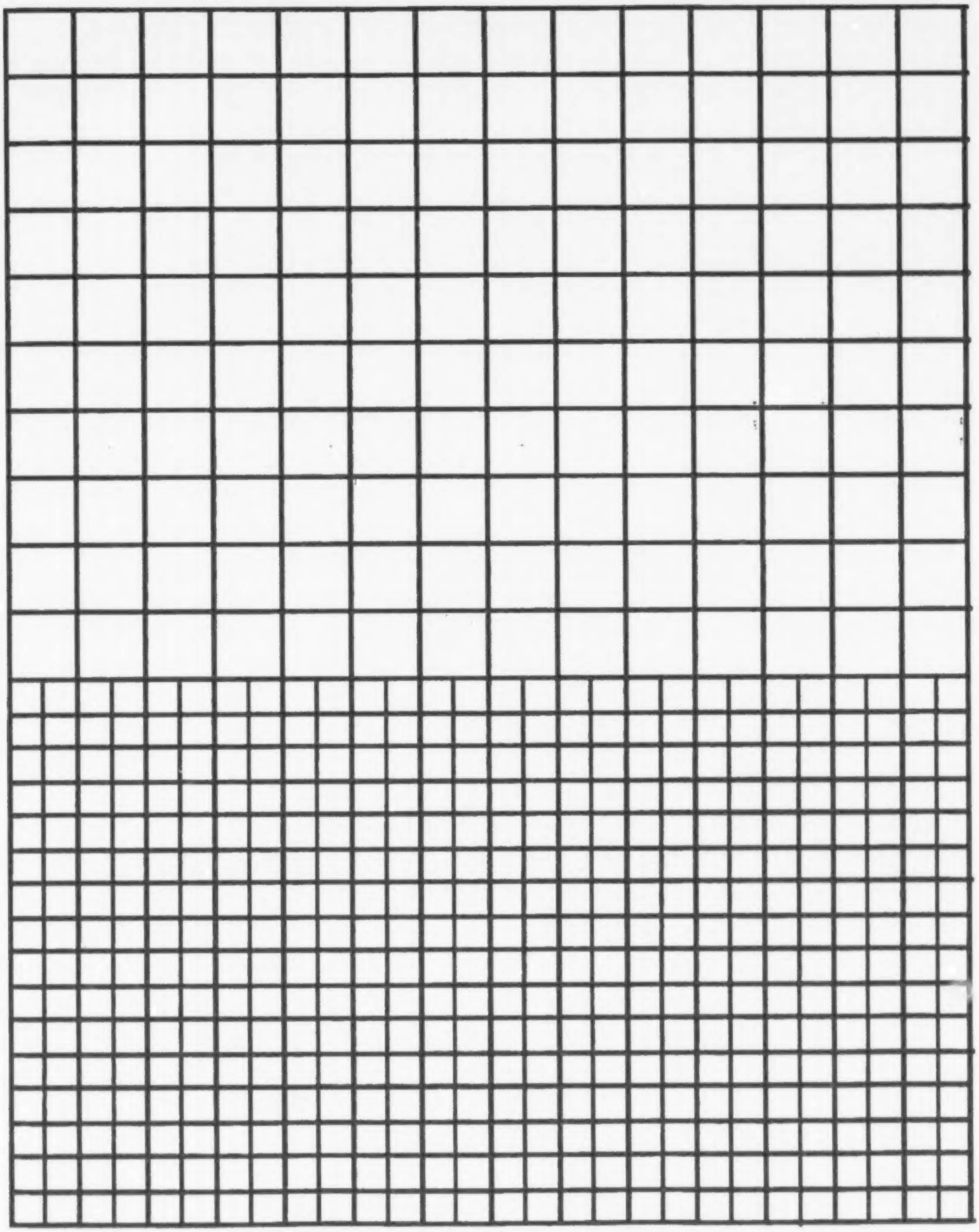
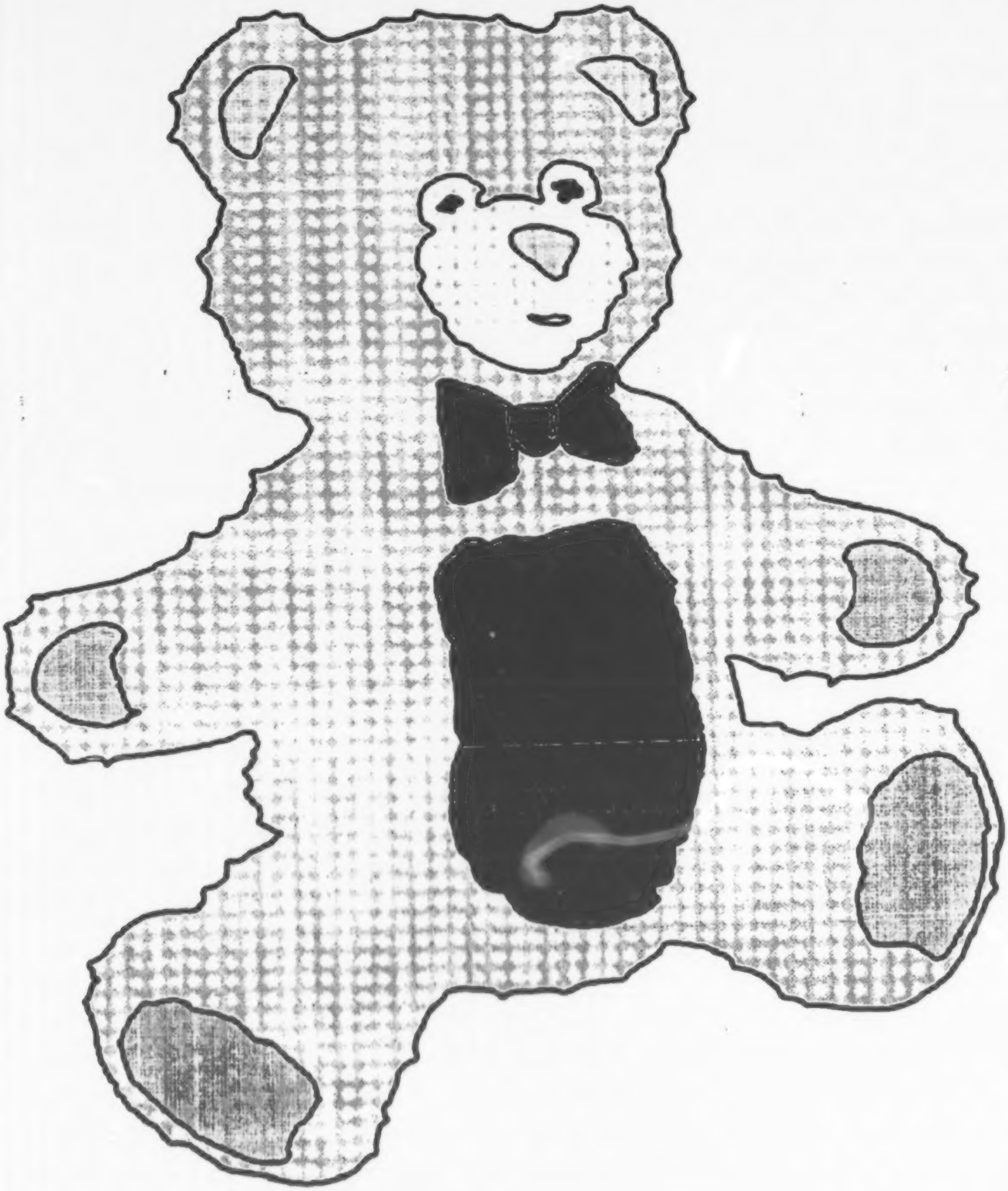


Figure LAND-L-28: Teddy Bear - Odyssey of the Eyes



Some Like it Hot!
Beginning Level

Purpose

To introduce students to the concepts of remote sensing and false colored images. Students create a map based upon temperature, using their hands as remote sensors. The challenge for the students in the project is to determine the location in a given area where an ice cube would melt the fastest and the location where an ice cube would last the longest.

Overview

As a satellite revolves around the Earth it takes pictures with a camera that is sensitive to a variety of different wavelengths. One of the main wave lengths sensed is thermal radiation. The sensor reads the amount of heat being radiated and makes a picture out of the different values. In this activity your students will use their hands as thermal sensors and explore an outside area with a variety of different land cover forms. The students will record the different values on a map of the area, just as a satellite does. When the students are done they will have a thermal map of their area.

Time

Three to five class periods

Level

Beginning

Prerequisites

Prior experience with field sketching is helpful.

A sunny day

Key Concepts

Orbiting satellites take photographs with cameras that are sensitive to a variety of different wavelengths.

One of the main wavelengths sensed is thermal radiation. The sensor reads the amount of heat being radiated and makes a picture out of the different values.

When students observe something without touching it they are actually using their eyes, ears, nose, and skin surface to remotely sense that object.

Skills

Observing a given area

Predicting the area that would melt an ice cube the fastest

Testing their predictions

Comparing different areas for thermal radiance

Mapping a thermal image

Materials and Tools

Ruler

Blank paper

Rope or string

Prism (optional)

Preparation

Classroom setup of bowls of hot water, ice, towels

Ice cubes each made from two teaspoons of water

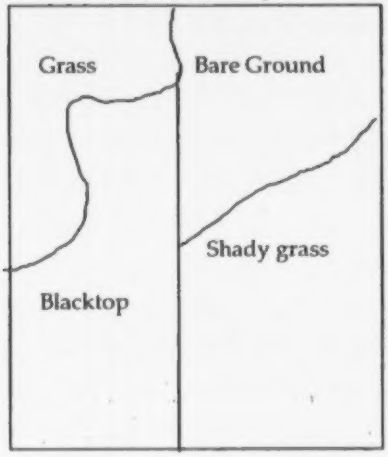
Confine or rope off area of approximately 5 - 10 meter square that contains a variety of land cover types. For example, an area may include blacktop, grass, and bare ground.

What To Do and How To Do It

1. Students should be placed in teams of two. Explain to the students that in a couple of days, they will be taken outside and given an ice cube. They will either be asked to find a location within a given area where they think the ice cube will melt the fastest or a location where they think their ice cube will be protected from melting.
2. Before exploring the outside area, the teacher sets up three to six examples in the classroom (bowl of ice, hot water, warm towel, area of tile floor). Students use their hands cupped downward to determine the relative temperature of each item. (Hands should not touch the item, they are remote sensors). Can they tell the differences between the examples if their eyes are closed?
3. This part of the activity is initiated outdoors in a confined or roped off area (approximate size 5-10 m square). Students will draw a field sketch of the square. On another piece of paper, the students should list the land covers they observe on site. The students should also draw a 12" ruler sized rectangle space reserved on the cover type listings. The teacher asks the class to make a list (or drawings in list form) of no more than 6 different land covers they observe. Some examples are rocks, asphalt, gravel, cut grass, long grass, shady grass, and sand. On the field sketch, the students should record a title for the project, date, time, location, compass directions, weather conditions, and team member names.
4. The students return to the site the following day with their list of land covers and use their hands, as practiced in the classroom, to measure the relative temperature of each land cover type and record this information next to each type of land cover listed so the information is arranged in some way from hottest to coolest.
5. Back in the classroom, the students divide the color rectangle on their key into boxes to represent the number of classes they observed and listed on site (see sample recording sheet). The teacher leads a class discussion over which colors will be used to represent the classes from hot to cold. Exploring and using the colors of the light spectrum as shown by the sun shining through a prism (if available) is suggested for setting color sequence. The teacher records the color sequence for the class to use. They use this sequence to color in the color boxes on the rectangle. (This box is the temperature key for the false colored image). From this chart, the students then complete the false coloring on their maps, coloring the land covers to match the information on the temperature scale.

Figure LAND-L-29: Sample Recording Sheet

Field Sketch Paper



Key

Land Cover	Color Rectangle
rocks	
gravel	
cut grass	
shady grass	
sand	
Blacktop	

6. In preparation for this part of the activity, the teacher makes ice cubes using two teaspoons of water. Ice cubes are taken out just prior to the activity and are wrapped in aluminum foil and placed in a cooler. The coin is tossed to determine whether they will have the challenge of melting the ice cube quickly or protecting the ice cube from melting. Each student team consults their map and chooses the location which best fits their challenge. The class is taken outdoors and each team is given an ice cube (covered with aluminum). They go to the chosen location, and upon a signal from the teacher, place the ice cube (minus the foil) down on the land cover. Upon giving the signal to begin, the teacher starts to record the time. When a students calls out "finished" the teacher gives a time, which the students records on a piece of paper. Students also record their selected location.

7. The teacher makes a table similar to the one below for students to display their results.

   The teacher writes the lowest minute time recorded and then asks the students who had between 1:00 and 1:29, for example, to place their results in the table. The process is repeated until all the data is recorded. A class discussion of the data follows and a new class temperature sensor map is created, showing the actual results of the ice cube activity. (This new map is an essential component for follow-up activities).

Acknowledgement: This is a revised version of the activity *Making an Icy Decision*, created by Lou Lambert for Gaia Crossroads, 1995.

Figure LAND-L-30: Some Like It Hot - Data Table

Group					
Time (min)	:00-:29	:30-:59	1:00-1:29	1:30-1:59	2:00-2:29

Some Like It Hot!
Intermediate Level

Purpose

To introduce students to the concepts of remote sensing and false colored images and to demonstrate exactly how a sensor displays heat sensing information in satellite photos and computer images

Overview

The students will use a thermometer to measure the heat radiating from the land cover types measured at the beginning level. They will recreate the thermal sensing map using a color code to depict thermal variations.

Time

Two to three class periods

Level

Intermediate

Key Concepts

- Orbiting satellites take photographs with cameras that are sensitive to a variety of different wavelengths.
- One of the main wavelengths sensed is thermal radiation or heat reflectance. The sensor reads the amount of heat being radiated and makes a picture out of the different values.
- When students observe something without touching it, they are actually using their eyes, ears, nose, and skin surface to remotely sense that object.

Skills

- *Observing* a given area
- *Measuring* different land types with a thermometer
- *Comparing* different areas for thermal radiance
- *Mapping* a thermal image

Materials and Tools

- Ruler
- Blank paper
- Rope or string
- Small thermometer
- Heavy paper cup
- Wire coat hanger

Preparation

A confined or roped off area of approximately 5-10 meter square that contains a variety of land cover types. For example, an area may include blacktop, grass, and bare ground.

Assemble the thermometer apparatus; however, if time permits, it may be constructed by students.

Prerequisites

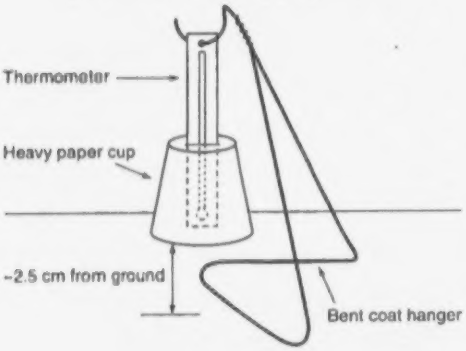
The beginning level activity is required.

The students need to know how to read a thermometer.

What To Do and How To Do It

1. Construct an infrared detector as shown in the illustration in Figure LAND-L-31: Thermometer Apparatus. This device is intended to measure the heat coming off an object and not from the air above. The paper cup works as a barrier to surrounding radiation. Look at the temperature gradients on the thermometer, assign colors to each range. For example, 0-5 = violet, 6-10=light blue, 11-15=aqua etc. until all degrees (in Celsius) are accounted for. These should be recorded in the Some Like It Hot Temperature Sheet found after *Some Like It Hot! Advanced Level.*

Figure LAND-L-31: Thermometer Apparatus



2. Using the thermometer apparatus, have the students measure the temperature coming from the same objects that they first measured with their hands in the beginning activity. Record the object temperature and appropriate color from the Some Like It Hot Temperature Sheet.
3. Staying in groups of two, the students go back out to the roped off area from the beginning activity and measure each land cover's temperature reflectance. Record the data and assign each cover type a color from the completed code on the Some Like It Hot Temperature Sheet.
4. Draw a map of the area. Label the temperature of each cover type and color the area with the appropriate color. On this map, the students should record the date, time, location and compass directions. Title this map, Temperature Sensor Map.

Discussion Questions

1. Compare the maps from the beginning activity and this activity. What are the differences?
2. By adding a temperature gradient how has the amount of color in the picture changed? Were there more or less total colors?
3. Are there any areas that were the same color on the heat sensor map that were different colors on the temperature sensor map? Why did this happen? If this did not happen on their map, the students should hypothesize why this could happen.
4. How close to the actual temperature reading were the students when they used their hands as heat sensors? The accuracy of the instrument in the beginning activity was their hands. Were some hands more sensitive than other students' hands?

Some Like it Hot!
Advanced Level

Purpose

To introduce students to the concepts of remote sensing and false colored images. Students will produce false color images of an area of their choice. By creating two images with different grid size, they will understand differences in image resolution.

Overview

The advanced level of *Some Like It Hot!* is designed to demonstrate how a satellite sensor reads information. The students will make a grid and use it to measure the thermal reflectance of the land cover visible within the squares of the grid. The end product will be a thermal map created in pixel form.

Time

Three to five class periods

Level

Advanced

Key Concepts

Orbiting satellites take photographs with cameras that are sensitive to a variety of different wavelengths.

One of the main wavelengths sensed is thermal radiation or heat reflectance. The sensor reads the amount of heat being radiated and makes a picture out of the different values.

When students observe something without touching it they are actually using their eyes, ears, nose, and skin surface to remotely sense that object.

Skills

Observing a given area

Measuring different land types with a thermometer

Comparing different areas for thermal radiance

Mapping a thermal image

Materials and Tools

Meter sticks

String

Tape

Paper cup thermometer apparatus from intermediate activity

Preparation

A premade grid as a demo would be useful. See Some Like It Hot Thermal Sensing Grid Sheet for example.

Prerequisites

A prerequisite for this activity is the intermediate activity.

What To Do and How To Do It

1. Students work in groups of three or four to construct a large grid. They use four meter sticks taped together for the outer frame. They create the grid by taping string across the width at the 20 cm intervals and then taping string across the length at 20 cm intervals. See the diagram below.
2. The student groups go outside and find an area that contains a variety of land cover types within a square meter. An example might be the edge of the blacktop where grass and sand are showing, or rocks or ice etc. The students draw and label the area.
3. The students place the grid over the area they sketched. In each square of the grid, they measure the temperature with the paper cup thermometer apparatus as in the Intermediate activity. They record their findings on the Some like It Hot! Thermal Sensing Grid Sheet found at the end of this activity.
4. In the classroom, they color in the grid using the color key developed in the intermediate activity. They have developed a thermal sensing map like the satellite images they use.

Part 2

1. Repeat the experiment with a finer grid, every 10 cm.
2. How does the change in grid size affect the map? Scientists refer to this change in grid size as change in resolution. As the resolution becomes finer, more and more specific information is displayed. Different resolutions are needed for different types of inquiry.

2a. Students compare both images within the group (20 cm and 10 cm)

- Which image has the most identifiable picture?
- Which image would be most useful for land cover assessment over a large area?
- Which image would be most useful for a land cover assessment over a small area?

2b. Students trade images with another group.

- Can they tell where that area is outside?
- What kinds of land cover items might be there?
- Which image gives them the best clues?

2c. Students compare images with the whole class. They discuss the value of thermal sensing to the world. As a possible extension, they can research some of the ways that thermal sensing is used.

What To Do Next

Predicting Snow Melt Patterns

Students use their temperature sensor map to predict a pattern of snow melt at the end of winter.

1. Explain to the students that the information they generated about the relative temperatures of land covers may help them predict the pattern of snow melt in their area. Review the data they collected during the temperature sensor map activity. Have them predict where the snow will melt the fastest in the spring and record those ideas and their reasons for later discussion.
2. Divide the teams into groups. Each team is assigned to a particular land cover within the site studied for the temperature sensor map activity. As spring nears, the students make daily trips to their location and record their observations.
3. As the snow melts to ground level, the students report land cover sightings. The sequence of land covers which become visible are recorded.
4. After all the data are recorded, the information is compared with the ice cube activity information gathered during the Beginning activity and any anomalies are explained by the students. Comparisons can be simplified by plotting observations onto wax paper or acetate and overlaying this plot on the original thermal map.

Table LAND-L-14: Temperature Sheet - Some Like It Hot

Some Like It Hot!

Name:

Date:

Temperature Sheet

Chart 1

	Range	Color
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

	Range	Color
11.		
12.		
13.		
14.		
15.		
16.		
17.		
18.		
19.		
20.		

Chart 2

	Object	Temperature	Color
1.			
2.			
3.			
4.			
5.			
6.			

Chart 3

	Land Cover	Temperature	Color
1.			
2.			
3.			
4.			
5.			
6.			

Table LAND-L-15: Thermal Sensing Grid - Some Like It Hot

Some Like It Hot
Name of Group:
Date:

Thermal Sensing Grid

What To Do Next

Predicting Patterns of Seed Germination

Students use their temperature sensor map to predict a pattern of seed germination in the spring.

1. Explain to the students that the information they generated about the relative temperatures of land covers may help them predict where seed sprouts may first appear in the spring. Review the data they collected during the temperature sensor map activity. Have them predict where they think sprouts will first appear in the spring and record those ideas and their reasons for later discussion.
2. Divide the teams into groups. Each team is assigned to a particular land cover within the site studied for the temperature sensor map activity. As spring nears, the students make daily trips top their location and record their observations.
3. As the snow melts to ground level, the students report vegetation sightings. The location of the first sprouts are recorded. Students use field guides to assist in the identification of the types of vegetation reported.
4. After all the data are recorded, the information is compared with the ice cube activity information gathered during the Beginning activity and any anomalies are explained by the students. Comparisons can be simplified by plotting observations onto wax paper or acetate and overlaying this plot on the original thermal map.

Discovery Area
Intermediate Level

Purpose

To use land cover maps to solve problems

Overview

Students will work to determine the location of a hospital while inflicting the least impact on the environment. They will utilize the unsupervised classified image from the remote sensing protocol to make their analysis and decision. The format of a town meeting will serve as the presentation of group work and for the overall class decision as to where to build the new hospital.

Time

Two to four class periods

Level

Intermediate

Key Concepts

Humans have an impact on the amount and type of land cover types.

Animals and plants are affected when land cover types change.

Humans need to be aware of the impact of land developments.

Skills

Analyzing different scenarios that change the land cover types of their areas

Predicting how the changes will affect the living organisms dependent upon that cover type

Evaluating solutions to various scenarios

Presenting their development plans to the class

Materials and Tools

A hard copy of the students' land cover map from the remote sensing protocols

Prerequisites

Students should have completed the remote sensing protocol.

Knowledge of the terms dominant, subdominant, rare, and isolated land cover types

Group presentation skills

What To Do and How To Do It

1. Divide the class into groups of three or four and discuss with your students what the land cover types are shown on the unsupervised clustered map. Have them list them in a chart like the one below.

a. Dominant	b. Subdominant	c. Rare or Isolated
1.	1.	1.
2.	2.	2.
3.	3.	3.
4.	4.	4.

2. Within the class thoroughly discuss each of the land cover areas. Pay close attention to living as well as non-living constituents. Have groups decide the three most desirable locations for a hospital, including parking lots and roads.

3. Using the chart, the students compare the land cover areas. How will the proposed development affect the plants and animals listed?
4. The students discuss the options with their group and narrow their decision to one.
5. The students construct a presentation board.
    - They enlarge the original classified image so that the land cover areas are easily recognizable.
    - Place the hospital, road, and parking lots that will be part of the development on the classified image basing the size on other buildings in the image.
6. The students prepare a presentation for the class. The presentation will take the form of a town meeting. Students will role-play local citizens and vote on the best place for placement of the hospital. Each presentation will be intended to persuade class mates that the team has picked the best spot.
7. After viewing all the other presentations, the students indicate which location they liked best and why.
8. After voting on an area, is there agreement with the class decision? Why or why not? Could there be more than one answer?

Site Seeing
Beginning Level

Purpose

The overall purpose of these pre-protocol activities is to introduce students to the concept of a system. The supporting concepts are boundaries, inputs, outputs, and feedback loops. The concept of a system will help students understand why they are conducting the biometry measurements on the 30 x 30 m Biology Study Site.

Overview

Students will investigate the environment of their 30 m x 30 m Biology Study Site. The students will use simple observational techniques to quantify and qualify their observations. The intention is that students will become curious about their system.

Purpose

The beginning activity will help students determine that a system's boundaries are often delineated depending upon the question the scientist wants to answer.

Time

Two or three class periods

Level

Beginning

Key Concepts

Your 30 m x 30 m Biology Study Site can be considered a system.

Your system contains certain elements within it such as trees, water, soil, rocks, and animals.

Your system has inputs such as sun's energy, water, carbon dioxide, oxygen, dust.

Your system has outputs such as water, carbon dioxide, oxygen, and heat.

Skills

Observing your system

Drawing your system

Interpreting maps as a data source

Materials and Tools

Paper

Colored pencils or crayons

Compasses

30 m x 30 m Biology Study Site sketch sheet

Camera

Preparation

The 30 m x 30 m Biology Study Site should be laid out.

Prerequisites

Students should understand why they are conducting the *Biometry Protocol* on this site.

Students should know how to use a compass.

Background

Scientists investigate natural systems for a variety of reasons. A *system* is any collection of *things* that have some influence on one another and appear to constitute a unified whole. The things can be almost anything, including objects, organisms, machines, ideas, numbers, or organizations. The question a scientist wants to answer often times determines the boundaries of the system. For example, an ecologist might want to study an entire ecosystem type such as wetlands to determine the amount of acreage still left in the world, or a specific species of wetland plant might be studied to experiment with different restoration techniques. Or a scientist might want to study one type of cell in a wetland plant to determine the plant's sensitivity to certain kinds of pollution. These studies would consider completely different factors determined by the scale of the study.

In the biometry protocols, we are looking at a certain system (30 m x 30 m Biology Study Site) for changes over time. These include changes in the growth rate of trees and the times of leaf drop and budding. By collecting data over many years, we can see if the data are consistent over time or if there is variation. To understand the data, students need to be familiar with the variety of factors affecting a system in order to understand the change. If they know what is coming in and out of the system and the basic processing of incoming materials within the system they will be able to see patterns that will help them make generalizations and predictions. For example, water comes into a forested system in the form of rain. Some of the water is stored in the trees and is used in growth. Some is released into the atmosphere. Some stays on the surface. Some percolates into the ground to join the water table.

Data variation could indicate changes in either the input, output, or the cycles that process matter and energy. In a series of drought years, the growth of the trees may be stunted due to the lack of water, stress, production, or fitness. Consistent temperature rises could cause a longer growing season resulting in an increase in production. This may be evident in leaves being on the trees longer or the trees increasing in size at a greater rate during those years, as seen in the rings or tree height. The data your class collect will help your students and the GLOBE scientists understand the system around them.

What To Do and How To Do It

1. Ask the students to sit with a piece of paper and a pencil in front of them. The students should close their eyes and imagine their perfect place in the whole world (e.g. beach forest, next to a fire, in a candy store). Give them a minute to imagine this image. Have them draw their special place on paper. How many of the students imagined a natural area for their special place?
2. Visit the center of your 30 m x 30 m Biology Study Site. Why did the class choose this size and shape study site? Answer the following questions for your 30 x 30 m Biology Study Site.
   a. What are the natural boundaries of this system?
   b. What do you see, smell, feel, hear?
   c. Is it wet/dry, warm/cool?
   d. Is there a lot of sunlight hitting the ground?
   e. How many different plants and animals live there?
   f. How many objects are non-living? Are they natural or man-made?
   g. What would your system look like at night?
   h. How would your system change in the different seasons?
3. Staying in the center of your site, ask the students to stand and draw each boundary – North, South, East, and West. These will be side views. Encourage them to be observant and draw details. Have your students save these diagrams in their GLOBE Science Notebooks.

   Note: You can have the students use the 30 m x 30 m Biology Study Site sketch work sheet to draw the site. Save the box in the middle of the work sheet for the micro sketch in step 4.
4. In order to obtain an increased knowledge of the Biology Study Site, have the students lay out on the ground a 1/3m x 1/3m square made of string. Have them draw what they observe within the square.

Have them answer questions a through h in number 2 above. What questions could they study within this square (or system) that they couldn't in the 30 m x 30 m Biology Study Site? How did changing the boundaries change what they saw?

5. Have the students take a soil sample from their individual plots with an auger, trowel, or shovel. Try to get at least 15 cm down into the soil and place it in a plastic sandwich bag. In the classroom, have the students observe the soil with the unaided eye and a 30X microscope. Now what parts do you see? Are there living things here or parts of living things?
6. From the center point, take a picture of each directional view. Once the pictures are developed, have the students compare their sketched views with the photographs. Have they drawn enough detail in their sketches to identify which picture corresponds with each compass direction? Are there parts of the system that they missed?

   Note: You can use the 30 m x 30 m Biology Study Site Sketch Work Sheet. The middle box can be use for the students' drawing.

Discussion Questions

1. What kinds of questions were asked when they changed the boundary of their system?
2. How does what happens in your neighbors square influence what happens in yours?
3. What is above your square and what is below it?
4. Does what is above and below affect your square in any way?
5. Generally what enters and leaves your system? Sunlight? Water? Seeds? Nuts? Animals?

Site Seeing
Intermediate Level

Purpose

To introduce students to the concept of a system. The supporting concepts are boundaries, inputs, outputs, and feedback loops. The concept of a system will help students understand why they are conducting the biometry measurements on the 30 x 30 m Biology Study Site. Students investigate the idea that every dynamic system has energy and matter. Inputs and outputs will vary depending upon the physical components of the site, the plant and animal life, the determined boundaries or scale of the study and the season of the year.

Overview

The intermediate level of Site Seeing builds upon the concepts presented in the beginning level. The class will travel to several different study sites including their 30 x 30 m Biology Study Site. At each site, students will explore a larger variety of system inputs and outputs, and will use more complex methods of data acquisition and analysis. The students will use the data from each site to compare and contrast the inputs and outputs of the environments.

Time

Three class periods

Level

Intermediate

Key Concepts

System boundaries will differ depending upon the question you are asking.
Systems contain certain elements such as trees, water, soil, rocks, and animals.
Systems have inputs such as sun's energy, water, carbon dioxide, oxygen, dust.
Systems have outputs such as water, carbon dioxide, oxygen, and heat.

Skills

Observing the components of the system and the inputs and outputs of the system
Measuring inputs and outputs of the system
Collecting data from the system
Interpreting the data collected about the various systems studied

Materials and Tools

String
30 x 30 m Biology Study Site
Thermometers
Rain gauges
Plastic sandwich bags
GLOBE Science Notebooks
Biology Field Site Work Sheet
Beaufort Scale Work Sheet
Heavy paper cup
Paper

Preparation

Use string to mark the borders of the 30 m x 30 m Biology Study Site.

Collect the data listed below at three different sites within your GLOBE Study Site– an open place such as a field or playground, near open water, and your Biology Study Site. Plan to visit the sites on the same day or on different days at about the same time.

Obtain necessary permission to visit the chosen sites, and check them for any safety hazards. Arrange for parents or other volunteers to accompany students to the sites.

You can use the Site Seeing Biology Field Site work sheet for students to record the data. Divide the class into three teams composed. Students should take the materials listed above and proceed with their missions at all three sites as follows.

Prerequisites

The rationale for the biometry protocol measurements on their 30 m x 30 m Biology Study Site.

The Beginning activity is recommended. If not used, students should understand the concept of system boundaries.

What To Do and How To Do It

1. Temperature – Ask the teams to measure each site's temperature at ground level, 2.5 cm deep in the soil, and at 0.5 m above the ground. To get the temperature of the soil below ground, carefully insert the tip of the thermometer into the ground. To get the temperature at or above ground level, you should insert the thermometer through a hole in the bottom of an upside-down heavy paper cup. The cup acts as a shield around the tip of the thermometer so that direct sunlight and other extraneous sources of heat do not cause inaccurate readings. The thermometer should be remain in one location until the temperature does not vary for 1-2 minutes.
2. Precipitation– What is the amount of rain during the last growing season? If you don't use the rain gauge from GLOBE, you can get the information from a meteorologist. A high school could use the GLOBE soil moisture of the area. Has it rained lately? What evidence is there – lakes, streams, water retainment areas, puddles?

   Have the students place a plastic sandwich bag over some living green leaves. Leave in place overnight. How much moisture is in the bag? Where did it come from? Where is it going?
3. Sunlight – When the sun is shining, look around your study site for signs of sunlight on the trees and on the ground. How much sunlight reaches the top of the trees? How much is reaching the ground? If sunlight is being absorbed by the plant, what happens to the sunlight? Is it being reflected (that means the leaves would be shiny and reflective like aluminum foil)? **Note:** Students will think that plants get their food from the soil and will not think the sun is used to make food during photosynthesis. They will think that sun helps plants to grow, but not sure how or why. Question students on how plants use sunlight in their life cycle?
4. Wind – How much wind is blowing in the sites? Are the leaves shaking in the breeze? Is the wind strong enough to bend small branches? Large branches? Have the students use a piece of paper as a temporary wind sock. See the Beaufort Scale Work Sheet. One student can hold the paper away from the body, while the others observe whether it hangs straight down or blows out at an angle. Have the students use the compass to determine from which direction the wind seems to be blowing.
5. Animal Life – Ask the teams to note the various kinds of animals at each site (insects, birds, reptiles, fish, frogs, or tadpoles). Students should record evidence of animals such as scat, tracks, burrows, or chewed leaves. Estimate the population of each animal type. Which is the most dominant?
6. Plant Life – Ask the teams to observe the various types of plants at each site (large trees, small trees, shrubs, small plants, grasses). Suggest that they record the most common types of plants found in each location. Estimate the population of each plant type? Which is the most dominant?
7. After the teams have had sufficient time to investigate each site, have them report their findings and share what they have learned. After listening to each other's reports, the class can complete a large composite class chart. Use this composite chart as a basis for discussing differences between the locations and interactions the students observe among the various elements.

Discussion Questions

1. How do the various sites differ in numbers or diversity of species of animals and plants? How are they different?
2. Which site had the highest air temperature? The lowest? The most wind? The least wind?
3. What relationship does light seem to have with air temperature? With soil moisture? With plants?
4. Which of the six variables studied seems most important for determining the character of the environment at each site? What makes you think so?
5. What are the inputs to the various systems? Which factors are outputs? Which of the six elements stays within the system? They can draw a picture or a flow chart of their sites.
6. Have students draw diagrams of their systems or make up a story about their system tracing the path of the sun through the system.

Further Investigations

1. Visit the sites selected in the Intermediate activities again at different seasons and repeat the investigation. How have the various factors changed? What factors influenced the change? What factors might have influenced the leaf on or off process during the course of the year?
2. Have students construct terrariums. Try to make the terrarium more like one of your above system sites. Add wind, moderate the temperature, water, and check for sunlight, add plants, mimic animal effects. Try to model your system based upon the data you received from your investigation. Try for seasonal variations. Can you do it? What limitations are there to the models? Can you develop the same cycles that exist in nature between the living and nonliving factors?

Figure LAND-L-32: Site Seeing - Biology Study Site Sketch Work Sheet

Date:

Name(s):

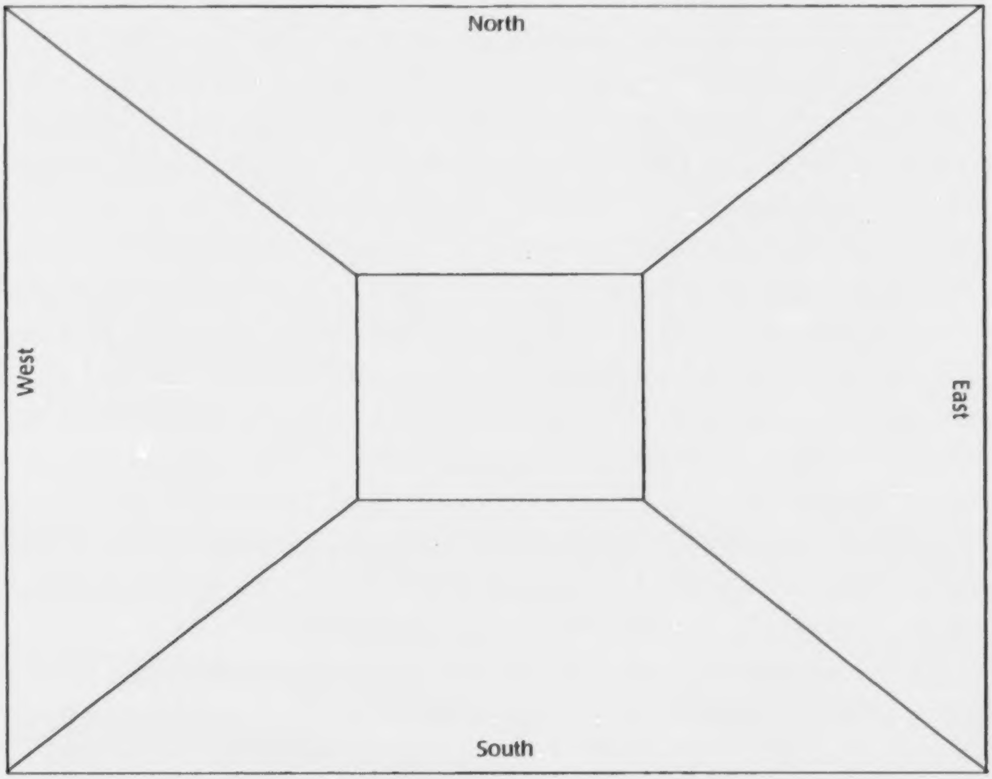

North
West
East
South

Figure LAND-L-33: Site Seeing - Biology Field Site Work Sheet

Site Seeing
Biology Field Site Work Sheet

Date: **Name:**

Study Site Type (circle one): Wetland Field 30 x 30 m Biology Study Site

Temperature (C) at: 0.5 m elevation:

Ground Level:

2.5 cm Depth:

Accumulated precipitation from the growing season (mm):

Sunlight:

Wind (Beaufort Scale):

Animal and Plant Life:

Table LAND-L-16: Beaufort Scale Work Sheet

Wind Speed		Beaufort Number	Wind Description	Observed Effects on Land
kmph	mph			
<1	<1	0	Calm	Calm, no movement of leaves
1–3	1–3	1	Light air	Slight leaf movement, smoke drifts, wind vanes moving
6–11	4–7	2	Light breeze	Leaves rustling, wind felt, wind vanes moving
12–19	8–12	3	Gentle breeze	Leaves and twigs in motion, small flags and banners extended
20–29	13–18	4	Moderate breeze	Small branches moving; raising dust, paper litter, and dry leaves
30–38	19–24	5	Fresh breeze	Small trees and branches swaying, wavelets forming on inland water ways
39–49	25–31	6	Strong breeze	Large branches swaying, overhead wires whistling, difficult to control an umbrella
50–61	32–38	7	Moderate gale	Entire trees moving, difficult of walk into wind
62–74	39–46	8	Fresh gale	Small branches breaking, difficult to walk, moving automobiles drifting and veering
75–87	47–54	9	Strong gale	Roof shingles blown away, slight damage to structures, broken branches littering the ground
88–101	55-63	10	Whole gale	Uprooted and broken trees, structural damage
102–116	64–73	11	Storm	Widespread damage to structures and trees, a rare occurrence
>117	>74	12–17	Hurricane	Severe to catastrophic damage

Seasonal Changes in Your Biology Study Site(s)

Purpose

To investigate seasonal changes by collecting data on spring bud-break and fall leaf senescence

Overview

In the Fall and Spring, students conduct measurements of seasonal changes in the green canopy and/or grasslands. In the spring, they measure bud-break, and in the Fall they measure leaf senescence. They do these measurements every week, for six weeks in the Fall and six weeks in the Spring. Students then investigate the rate of change based on the data they collected.

Time

Two class periods to introduce the activity and explore the data

Also, a small group of students needs to collect the data, one period per week, for a six weeks in the Fall and six weeks in the Spring.

Level

Intermediate or Advanced

Key Concepts

In the Spring, there is a period of bud-break, in which leaf buds appear and grow.

In the Fall, there is a period of senescence, in which actively growing plant material dies.

Skills

Measuring tree canopy

Analyzing data for Spring and Fall changes over time

Materials and Tools

Tubular Densiometer

See Land Cover/Biology Protocol *Identification of Dominant and Co-Dominant Species.*

Prerequisites

Students should know how to use the tubular densiometer. See Land Cover/Biology Protocol *Identification of Dominant and Co-Dominant Species.*

Background

This learning activity focuses on the changing lengths of growing seasons for different parts of the Earth. In order to determine the length of growing season for your area, researchers, and you and your students, can monitor the development of a green canopy and/or grasslands from spring "bud-break" to autumnal senescence (the death of actively growing plant material.) Satellite data and images can be used to track the "green wave" in the spring, as it moves from south to north in the northern hemisphere, and the "brown wave" in the fall, as it moves from north to south. In the southern hemisphere the "green wave" moves in the reverse direction, from north to south and the "brown wave" moves from south to north.

One of the disadvantages of using satellite data is that the spatial resolution may be poor. This means that many ground features such as individual trees or stands of trees will not be seen directly. Thus researchers working with satellite imagery need more detailed information about what is happening in the vegetated land cover types that are contributing to the data monitored by the satellites. Two very critical times of the year are the "spring" leaf-out and the "fall" senescence, for they define the length of the growing season for a particular place on the Earth's surface. Your studies in this activity will add to your understanding of these critical times in your area in a very significant way.

Depending on your location, your climate or vegetation types may not lend themselves to the observation of the seasonal events described here.

What To Do and How To Do It

If your GLOBE Biology Study Site contains deciduous trees:

Bud-break:

1. Using the 30 m x 30 m Biology Study Site, select a day in early spring just as leaves are beginning to emerge to conduct an assessment of percent canopy closure, using the tubular densiometer method. See Land Cover/Biology Protocol *Identification of Dominant and Co-Dominant Species*.
2. Once per week, for the next five weeks, (for a total of six weeks) conduct the same canopy closure assessment, using the same method.
3. Record your data, and save it for study of the year-to-year changes in bud-break.

Senescence:

1. Using the same 30 m X 30 m Biology Study Site, select a day when the first signs of autumnal color change in foliage are seen. Conduct an assessment of percent canopy closure (see Land Cover/ Biology Protocol *Identification of Dominant and Co-Dominant Species*), with the following change in method.
2. Measure canopy closure, using the tubular densiometer, but instead of recording just (+'s) and (-'s), record "g" if you see green leaves, "b" if you see brown or colored leaves, and (-) if you see no foliage. This is the same method you used for brown and green ground cover.
3. Calculate the percentages of green and brown canopy in the same manner as you calculated ground cover.
4. Once per week, for the next five weeks, repeat this observation.
5. Record your data and save it for year-to-year studies of changes in senescence.

Grassland areas: Just as the timing of bud-break and senescence are important indicators in forests, the timing of changes in grassland vegetation is also an important indicator. In grassland, the timing of the beginning and end of active growth, the occurrence of flowering and fruiting, and senescence are significant, observable changes that describe the growing season, that can be measured by you and your students.

If your GLOBE Biology Study Site contains grasses:

Bud-break:

1. Using the 30 m X 30 m Biology Study Site (in this case, one in which grass is dominant or co-dominant), select a day in early spring just as the grasses are beginning to turn green.
2. Measure the percentages of brown and green ground cover in the same manner described in the ground cover protocol.
3. Once per week, for the next five weeks, repeat this ground cover survey.

Senescence:

1. Repeat the ground cover measurements above when grasses begin to turn brown. The timing of the browning may or may not coincide with the fall period in your area; if, for example, a lack of rain makes the grass turn brown. You will need to observe your grasslands area to decide when to begin this measurement.

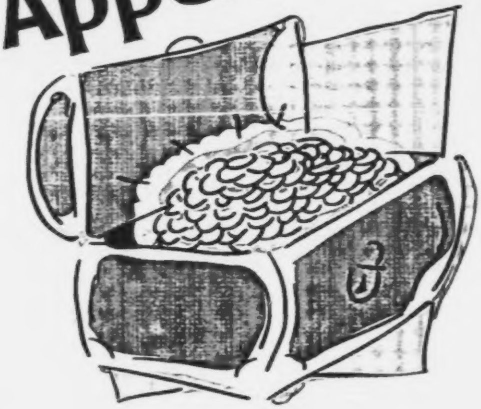
Going Farther – An Extension

A significant event in grasslands is the formation of flowering heads and fruiting heads. Since it may be difficult for you and your students to determine the difference between grass flowers and fruits, simply note the time of year when the grass changes from growing leaves (grass blades) to growing a central stalk, which elongates, eventually becoming topped by the flowering/ fruiting head. Note the timing of this event, within one week, and record this it in your data archive.

Changes from year-to-year in the timing and lengths of the events measured in this exercise will give you and your students a way of relating changes in your other GLOBE measurements (temperature, precipitation, etc.) to their effects on your local environment.

To help you and your students evaluate these seasonal changes, see the suggestions in the *Seasons Investigation* later in the GLOBE Teacher's Guide.

Appendix



Clinometer Sheet

Table of Tangents

Dominant/Co-Dominant Vegetation Data Work Sheet

Field Data Work Sheet

MUC Classification Data Work Sheet

Glossary of Terms in the Modified UNESCO Classification Scheme (MUC)

Glossary

Figure LAND-A-1: Clinometer Sheet

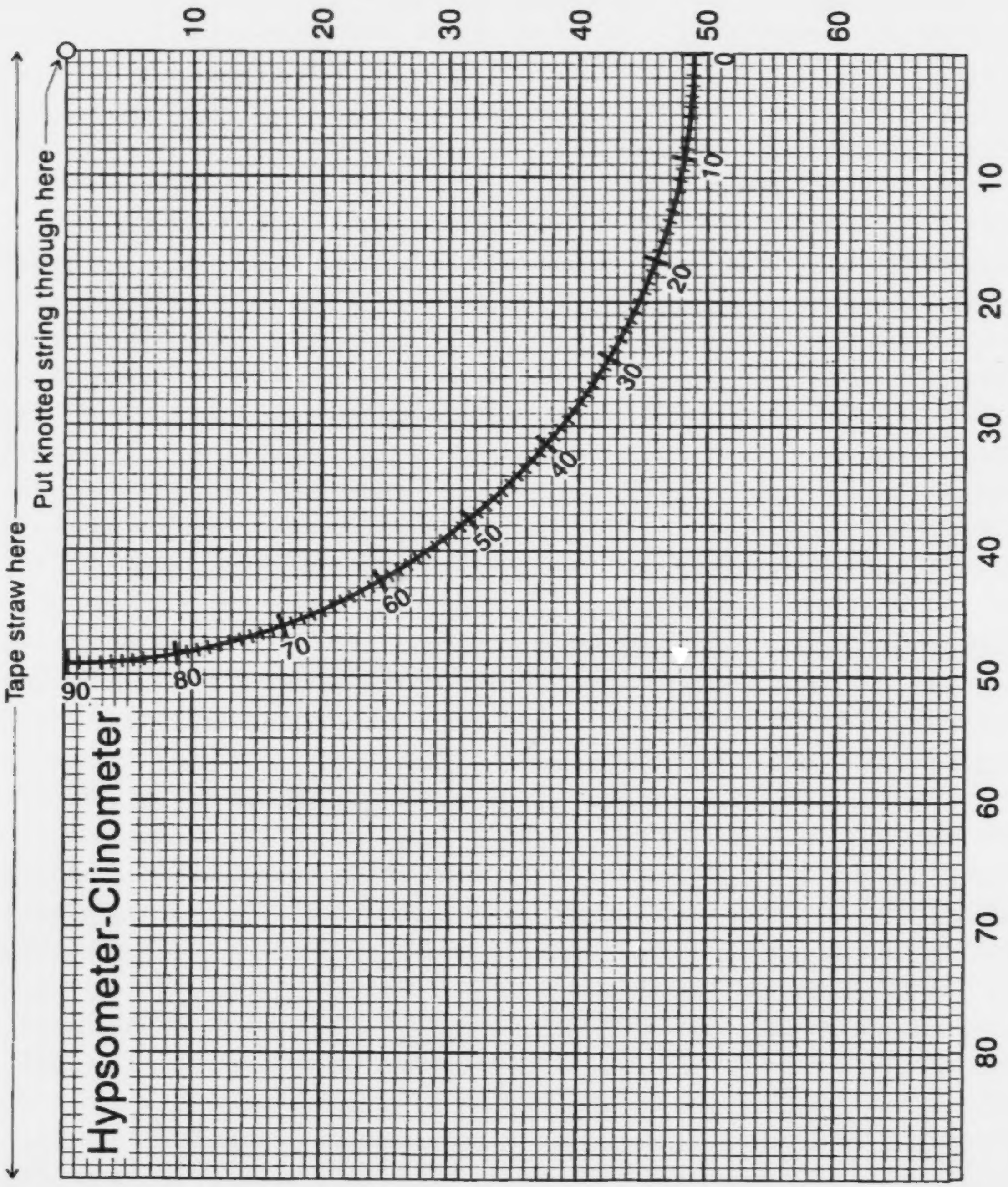

Tape straw here
Put knotted string through here
Hypsometer-Clinometer
10
20
30
40
50
60
0
10
20
30
40
50
60
70
80
90
10
20
30
40
50
60
70
80

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Table LAND-A-1: Table of Tangents

Angle	Tan.	Angle	Tan.	Angle	Tan.	Angle	Tan.	Angle	Tan.
1°	.02	17	.31	33	.65	49	1.15	65	2.14
2	.03	18	.32	34	.67	50	1.19	66	2.25
3	.05	19	.34	35	.70	51	1.23	67	2.36
4	.07	20	.36	36	.73	52	1.28	68	2.48
5	.09	21	.38	37	.75	53	1.33	69	2.61
6	.11	22	.40	38	.78	54	1.38	70	2.75
7	.12	23	.42	39	.81	55	1.43	71	2.90
8	.14	24	.45	40	.84	56	1.48	72	3.08
9	.16	25	.47	41	.87	57	1.54	73	3.27
10	.18	26	.49	42	.90	58	1.60	74	3.49
11	.19	27	.51	43	.93	59	1.66	75	3.73
12	.21	28	.53	44	.97	60	1.73	76	4.01
13	.23	29	.55	45	1.00	61	1.80	77	4.33
14	.25	30	.58	46	1.04	62	1.88	78	4.70
15	.27	31	.60	47	1.07	63	1.96	79	5.14
16	.29	32	.62	48	1.11	64	2.05	80	5.67

Example: Assume you have established a baseline distance of 60 meters. Assume that you have measured the tree top to an angle of 24°. From the Table, you will see that the tangent of 24° is 0.45. Therefore, the tree height is 60m x 0.45 = 27 meters. By adding the height of the eyes of the observer (1.5m), the total tree height is 28.5 meters.

Land Cover/Biology

Dominant/Co-Dominant Vegetation Data Work Sheet

	Use these columns to determine: Overall Canopy & Ground Cover		Use these columns to determine: Dominant & Co-Dominant Canopy Species or Ground Vegetation Type		Use this column to derive MUC for forest or woodland
	Canopy Observations + = Canopy - = Sky	**Ground Observations** G = Green Cover B = Brown Cover - = No Cover	**Canopy Species/Common Name**	**Ground Vegetation Type** graminoid or forb	**Canopy Type** E = Evergreen D = Deciduous S = Sky
1					
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3					
4					
5					
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8					
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10					
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39					
40					

(See Work Sheet for Calculations)

Canopy Cover	Ground Cover
%	%

Dominant Canopy Species or Ground Vegetation Type:

Co-Dominant Canopy Species or Ground Vegetation Type:

Dominant/Co-Dominant Vegetation Data Work Sheet (continued)

Determining Canopy Cover:

Total +'s =

Total –'s =

Total Observations =

% Canopy Cover
(+'s/Total Observations) = ← **Report This!**

Determining Ground Cover:

Total G's =

Total B's =

Total –'s =

Total Observations =

% Ground Cover
(G+B/Total Observations) = ← **Report This!**

If Forest or Woodland Cover Type:

Determining Percentage Evergreen and Deciduous:

Total number of E's =

Total number of D's =

Total Canopy (E + D) =

% Evergreen
(E's/Total Canopy) =

% Deciduous
(D's/Total Canopy) =

Use to determine MUC if forest or woodland See MUC Protocol

If Herbaceous Cover Type:

Determining Percentage graminoid or forb:

Total number of grasses =

Total number of forbs =

Total Observations =

% Grass
(Grass/Total Observations) =

% Forbs
(Forbs/Total Observations) =

Use to determine MUC if herbaceous See MUC Protocol

Land Cover/Biology Investigation

Field Data Work Sheet

★For Land Cover Sites Only:

★Type of Site:
☐ Biology Site
☐ Land Cover Site

☐ Training Site
☐ Validation Site

☐ Qualitative Site
☐ Quantitative Site

Site Name:________________ ★Country/State/City:______________________

★GPS Location: Lat.___________ Long.___________

★Date:________ ★Time:_________ Recorded by:_____________________

MUC Level 1 Land Cover Class: Name: _______ Code:_______

If class 2, 3, or 5 - 9, **Stop Here.** If this is a Qualitative site, **Stop Here.**

Dominant & Co-Dominant Vegetation (Genus & Species) – See Dominant/Co-Dominant Vegetation Field Form.

If Forest or Woodland: ★Dominant:_____ _____ ★Co-Dominant:_____ _____

If Herbaceous:

★ Dominant: ☐ Grass ☐ Forb

★ Co-Dominant: ☐ Grass ☐ Forb ☐ Trees: Genus:______ Species:______

Biometry Data

Record Data from the *Dominant/Co-Dominant Vegetation Work Sheet*

Canopy Cover:

Total +'s____ Total –'s____ Total Observations_____ % Canopy_________

Ground Cover:
Total G's____ Total B's____ Total -'s____ Total Observations_____ % Ground Cover__

Percent Evergreen and Deciduous:
Total E's____ Total D's____ Total Canopy (E + D)____ % Evergreen____ % Decid.___

Percent Graminoid or Forb:
Total Grasses____ Total Forbs____ Total Obs.____ % Grass____ % Forbs____

Dominant Species:________ ________

Tree Height:___m ___m ___m ___m ___m

Tree DBH:___cm___cm___cm___cm___cm

If Grass-
Green Biomass:___g/m^2 ___g/m^2 ___g/m^2

Brown Biomass:___g/m^2 ___g/m^2 ___g/m^2

Co-Dominant Species:________ ________

Tree Height:___m ___m ___m ___m ___m

Tree DBH:___cm___cm___cm___cm___cm

If Grass-
Green Biomass:___g/m^2 ___g/m^2 ___g/m^2

Brown Biomass:___g/m^2 ___g/m^2 ___g/m^2

Biometry Summary

★Canopy Cover:____%

★Ground Cover: Green:____%
Brown:____%
Total: _____%

★Average Tree Height:____m

★Average Tree DBH:____cm

★Avg. Green Biomass:____g/m^2 ★Avg. Brown Biomass:____g/m^2 ★Total Biomass:____g/m^2

MUC Land Cover Class

★Level 2 Name:________ Code:________

★Level 3 Name:________ Code:________

★Level 4 Name:________ Code:________

Notes:____

____

Photographs:____

____

Phenology (optional)

★Event (check one): ☐ Bud-Break ☐ Senescence

(Do canopy cover or ground cover measurements - other side)

★Canopy Cover:____% ★Percent Green in Canopy (estimate):____%

★Ground Cover: Green____% Brown____% Total:____%

Land Cover/Biology Investigation

MUC Classification Data Work Sheet

Sample Number	Site Name	Student Classification from MultiSpec or Manual Interpretation	Validation Data from ground visitation	Correct	Incorrect

Glossary of Terms in the Modified UNESCO Classification Scheme (MUC)

This glossary provides definitions, decision criteria, and examples of all the land cover types outlined in the Modified UNESCO Classification Scheme (MUC). It should be used as the primary reference to determine what land cover classes to report in the Land Cover Module Protocols.

The glossary contains four columns of information:

1. The MUC classification code (used to report land cover types in the Land Cover and Accuracy Assessment Protocols)
2. The name of the land cover class
3. The MUC class level
4. The definitions, decision criteria, and examples

MUC Code	Name of Land Cover Class	MUC level	Definitions, Decision Criteria, and Examples
0	Closed Forest	level 1	Formed by trees at least 5 meters tall with their crowns interlocking. Total canopy cover is greater than 40%.
01	Mainly Evergreen Forest	level 2	The canopy is never without green foliage . . .
011	Tropical Wet Forest	level 3	Often called a tropical rain forest. Consisting mainly of broad-leaved evergreen trees . . .
0111	Lowland Forest	level 4	Consists of fast growing trees, many exceeding 50 meters tall and usually forming an uneven canopy . . .

The land cover types are organized numerically in the same order as the classes appear in the MUC Classification Scheme. Miscellaneous terms used in the glossary are defined following the numbered MUC definitions.

Be sure to note the difference between determining the percentage ground coverage (the entire area which is under the canopy or foliage of the vegetation) and the percentage species composition. The overall canopy or ground coverage determines the dominant level 1 land cover type for the specific area on the satellite image. The percent species composition of the dominant cover type (from level 1) determines which level 2 land cover classification is appropriate. Levels 3 and 4 are more specific descriptions of plant communities and may be determined by either ground coverage or percent species composition as defined in the glossary.

For an example, see the following heading in the *miscellaneous terms* section of the glossary: **Classification using MUC, % Cover vs. % Species Composition**

References: *A land use and land cover classification system for use with remote sensor data.* J.R. Anderson, E.E. Hardy, J.T. Roach, and R.E. Witmer. U.S. Geol. Survey. Prof. Pap., 1976.

Classification of Wetlands and Deepwater Habitats of the United States. L.M. Cowardin, V. Carter, F.C. Golet, and E.T. LaRoe. U.S. Fish and Wildlife. Services. FWS/OBS-79/31, 1979.

International Classification and Mapping of Vegetation. United Nations Educational, Scientific and Cultural Organization. Switzerland: UNESCO, 1973.

NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation. J.E. Dobson et al. NOAA Technical Report NMFS 123, 1995.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
0	Closed Forest	level 1	Formed by trees at least 5 meters tall with their crowns interlocking. Total canopy cover is greater than 40%.
01	Mainly Evergreen Forest	level 2	The canopy is never without green foliage. At least 50% of the trees that reach the canopy are evergreen. Individual trees may shed their leaves.
011	Tropical Wet Forest	level 3	Often called a tropical rain forest. Consisting mainly of broad-leaved evergreen trees, neither cold nor drought resistant. Truly evergreen, i.e. the forest canopy remains green all year though a few individual trees may be leafless for a few weeks. Leaves of many species have" drip tip" .
0111	Lowland forest	level 4	Consists of fast growing trees, many exceeding 50 meters tall and usually forming an uneven canopy. Undergrowth is sparse, lichen and green algae are present, and climbing vines are absent.
0112	Submontane forest	level 4	Trees form an even canopy. Forbs are common in the undergrowth. Vascular epiphytes and vines are abundant, e.g., Atlantic slopes of Costa Rica.
0113	Montane forest	level 4	Trees are less than 50 meters tall, have crowns that extend relatively far down the stem and have rough bark. Usually ferns, herbs, mosses, and small palms are abundant in the undergrowth, e.g., Sierra de Talamanca, Costa Rica.
0114	" Subalpine" forest	level 4	Occurs at elevations above montane forests, with characteristic vegetation which is dependent on latitude.
0115	Cloud forest	level 4	Trees are gnarled , have rough bark and are rarely greater than 20 meters tall. Tree crowns, branches and trunks are burdened with epiphytes and vines, e.g., Blue Mountains, Jamacia.
012	Tropical and Subtropical Evergreen Seasonal	level 3	Consisting mainly of broad-leaved evergreen trees. Foliage reduction during the dry season is noticeable, often as partial shedding. Transitional between Tropical Wet Forest and Tropical and Subtropical Semi-deciduous.
0121	Lowland forest	level 4	Consists of fast growing trees, many exceeding 50 meters tall and usually forming an uneven canopy. Undergrowth is sparse, lichen and green algae are present, and climbing vines are absent.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
0122	**Submontane forest**	level 4	Trees form an even canopy. Forbs are common in the undergrowth. Vascular epiphytes and vines are abundant.
0123	**Montane forest**	level 4	Trees are less than 50 meters tall, have crowns that extend relatively far down the stem and have rough bark. Evergreen shrubs are more common than tree ferns in the undergrowth.
0124	**" Subalpine" forest**	level 4	This forest resembles the Winter-rain Evergreen Broad-leaved Sclerophyllous dry forest and usually occurs above the cloud forest. Trees are mostly evergreen sclerophyllous trees, smaller than 20 meters with little or no undergrowth, few climbing vines, and few epiphytes.
013	Tropical and Subtropical Semi-deciduous (upper canopy drought deciduous)	level 3	Most of the upper canopy trees are drought-deciduous; many of the understory trees and shrubs are evergreen and more or less sclerophyllous. However, evergreen and deciduous woody plants and shrubs may occur mixed within the same layer. Nearly all trees have bud protection and leaves without " drip tips" . Trees have rough bark, except some bottle trees, which may be present.
0131	Lowland forest	level 4	The taller trees may be bottle trees (e.g.,Ceiba). There are practically no epiphytes present. The undergrowth is composed of shrubs and seedlings. Succulents such as thin-stemmed caespitose cacti are also present. Vines and sparse layer of herbaceous vegetation may also be present.
0133	Montane or cloud forest	level 4	This forest is similar to a Semi-deciduous Lowland Forest, however, the canopy is lower and covered with xerophytic epiphytes such as *Tillandsia usneoides*.
014	Subtropical Wet Forest	level 3	Present only locally and in small fragmentary stands, because the subtropical climate typically has a dry season. Subtropical Wet Forest (e.g., in Queensland, Australia and Taiwan) usually grades into tropical wet forest. Some shrubs may grow in the understory. Seasonal temperature change occurs between summer and winter.
0141	Lowland forest	level 4	Consists of fast growing trees, many exceeding 50 meters tall and usually forming an uneven canopy. Undergrowth is sparse, lichen and green algae are present, and climbing vines are absent.
0142	Submontane forest	level 4	Trees form an even canopy. Forbs are common in the undergrowth. Vascular epiphytes and vines are abundant.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
0143	Montane forest	level 4	Trees are less than 50 meters tall, have crowns that extend relatively far down the stem and have rough bark. Usually ferns, herbs, mosses, and small palms are abundant in the undergrowth.
0144	ÒSubalpineÓforest	level 4	Occurs at elevations above montane forests, with characteristic vegetation which is dependent on latitude.
0145	Cloud forest	level 4	Trees are gnarled, have rough bark and are rarely greater than 20 meters tall. Tree crowns, branches and trunks are burdened with epiphytes and vines.
015	Temperate and Subpolar Evergreen Wet Forest	level 3	Occurs only in the extremely oceanic, nearly frost-free climates of the southern hemisphere, mainly in Chile. Consisting mostly of truly evergreen hemisclerophyllous trees and shrubs. Rich in epiphytic mosses, liverworts, lichens that grow on trees, and in ground-rooted herbaceous ferns.
0151	Temperate evergreen wet forest	level 4	Trees are greater than 10 meters tall. Vascular epiphytes and vines may be present.
0152	Subpolar evergreen wet forest	level 4	Trees are less than 10 meters tall and often have reduced leaf size. There are no vascular epiphytes present.
016	Temperate Evergreen Deciduous Broad-leaved Forest	level 3	Requires adequate summer rainfall. This is a mixed evergreen-deciduous class. The dominant trees are mainly hemi-schlerophyllous evergreen trees (more than 50% of the canopy) and shrubs, and the subdominant trees are deciduous broad-leaved trees and shrubs (more than 25% of the canopy). Rich in perennial herbaceous plants. Very few or no vascular epiphytes and vines.
0161	Lowland forest	level 4	Consists of fast growing trees, many exceeding 50 meters tall and usually forming an uneven canopy. Undergrowth is sparse, lichen and green algae are present, and climbing vines are absent.
0162	Submontane forest	level 4	Trees form an even canopy. Forbs are common in the undergrowth. Vascular epiphytes and vines are abundant.
0163	Montane forest	level 4	Trees are less than 50 meters tall, have crowns that extend relatively far down the stem and have rough bark. Usually ferns, herbs, mosses, and small palms are abundant in the undergrowth.
0164	" Subalpine" forest	level 4	Occurs at elevations above montane forests, with characteristic vegetation which is dependent on latitude.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
017	Winter-Rain Evergreen Broad-leaved Sclerophyllous	level 3	Often understood as Mediterranean, but present also in south-western Australia, Chile, and other locations. The climate has a pronounced summer drought. The trees are mainly of sclerophyllous evergreen trees and shrubs, most of which have rough bark. There is very little herbaceous undergrowth. No vascular and few epiphytic bryophytes (mosses and liverworts) and lichens, but evergreen woody vines are present.
0171	Lowland and submontane > 50 m	level 4	Dominated by trees over 50 meters tall (more than 50% of the canopy) such as giant eucalypts, e.g., *Eucalyptus regnans* in Victoria and E. *diversicolor* in Western Australia.
0172	Lowland and submontane < 50 m	level 4	Dominated by trees less than 50 meters tall (more than 50% of the canopy), e.g., Californian live-oak forest.
018	Tropical and Subtropical Evergreen Needle-leaved	level 3	Consisting mainly of needle-leaved or scale-leaved evergreen trees (more than 50% of the canopy). Broad-leaved trees may be present. Vascular epiphytes and vines rarely present.
0181	Lowland and submontane	level 4	E.g., the pine forests of Honduras and Nicaragua.
0182	Montane and subalpine	level 4	E.g., the pine forest of the Philippines and southern Mexico.
019	Temperate and Subpolar Evergreen Needle-leaved	level 3	Consisting mainly of needle-leaved or scale-leaved evergreen trees (more than 50% of the canopy), but broad-leaved trees may be present. Vascular epiphytes and vines are rarely present.
0191	Giant forest	level 4	Dominated by trees (more than 50% of the canopy) greater than 50 meters tall, e.g., *Sequoia* and *Pseudo-tsuga* forest in the Pacific West of North America.
0192	Rounded crowns	level 4	Dominated by trees 45-50 meters tall (more than 50% of the canopy), with broad, irregularly rounded crowns, e.g., *Pinus* spp.
0193	Conical crowns	level 4	Dominated by trees 45-50 meters tall (more than 50% of the canopy), with conical crowns, e.g., *Picea, Abies,* California red fir forests.
0194	Cylindrical crowns	level 4	Dominated by trees 45-50 meters tall (more than 50% of the canopy), with crowns with very short branches and a narrow cylindrical shape.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
02	Mainly Deciduous Forest	level 2	The majority of trees (more than 50% of the canopy) shed their foliage simultaneously in connection with the unfavorable season (drought or cold).
021	Tropical and Subtropical Drought-deciduous	level 3	The unfavorable season is mainly characterized by drought, in most cases winter-drought. Foliage is shed regularly every year. Most trees have relatively thick, fissured bark.
0211	Broad-leaved lowland and submontane	level 4	Practically no evergreen plants in any stratum, except some succulents. Woody and herbaceous vines and deciduous bottle-trees are present. Sparse herbaceous vegetation present in the undergrowth, e.g., the broad-leaved deciduous forest of north-western Costa Rica.
0212	Montane and cloud forest	level 4	Some evergreen species are present in the understory. Drought resistant epiphytes are present or abundant, often in the bearded form (e.g., *Usnea* or *Tillandsia usneoides*). This formation is not frequent, but well developed, e.g., in northern Peru.
022	Cold-deciduous Forest with Evergreen Trees and Shrubs	level 3	The unfavorable season is mainly characterized by winter frost. Deciduous broad-leaved trees are dominant (more than 50% of the canopy), but evergreen species are present (more than 25% of the canopy) as part of the main canopy or the understory. Climbers and vascular epiphytes are scarce or absent.
0221	With evergreen broad-leaved trees and climbers	level 4	Rich in epiphytes and mosses. Vascular epiphytes may be present at the base of tree stems. Climbing vines may be common on flood plains. *Ilex aquifolium* and *Hedera helix* in western Europe and *Magnolia* spp. in North America are examples of this class type.
0222	With evergreen needle-leaved trees	level 4	E.g., the maple-hemlock or oak-pine forests of Northeastern, U.S.A.
023	Cold-deciduous Forests without Evergreen Trees	level 3	Deciduous trees are absolutely dominant (more than 75% of the canopy). Evergreen herbs and some evergreen shrubs (less than 2 meters tall) may be present. Climbers insignificant but may be common on flood plains; vascular epiphytes are absent (except occasionally at the lower base of the tree); mosses, liverworts and particularly lichens are always present.
0231	Temperate lowland and submontane broad-leaved	level 4	Trees are up to 50 meters tall. Epiphytes are primarily algae and crustose lichens.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
0232	Montane or boreal	level 4	Trees may be up to 50 meters tall, but in montane or boreal forest normally not taller than 30 meters. Epiphytes are primarily lichens and bryophytes. This class includes lowland or submontane in topographic positions with high atmospheric humidity.
0233	Subalpine or subpolar	level 4	Trees are not taller than 20 meters and have gnarled trunks. Epiphytes are lichens and bryophytes and are more abundant than in the montane class (0232). This class often grades into woodland.
03	Extremely Xeromorphic (dry) Forest	level 2	Dense stands of trees and shrubs adapted to dry conditions, such as bottle trees, tuft trees with succulent leaves and stem succulents. Undergrowth has shrubs adapted to dry conditions, succulent perennial herbs and annual and perennial herbaceous plants. Often grades into woodlands.
031	Sclerophyllous-dominated Extremely Xeromorphic	level 3	Vegetation similar to Xeromorphic Forest, with predominance of sclerophyllous trees, many of which have bulbose stem bases largely embedded in the soil.
032	Thorn Forest	level 3	Species with thorns are dominant (more than 50% of the canopy).
0321	Mixed deciduous-evergreen thorn forest	level 4	Both deciduous species and evergreen species are more than 25% of the tree canopy. See definitions of Mainly Evergreen Forest, class 01 and Deciduous, class 02.
0322	Purely deciduous thorn forest	level 4	Deciduous thorn species are absolutely dominant (more than 75% of the canopy). See definition of Deciduous Forest, class 02.
033	Mainly Succulent Forest	level 3	Tree-formed (scapose) and shrub-formed (caespitose) succulents are very frequent (more than 50% of the canopy), but other trees and shrubs adapted to dry conditions are usually present as well.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
1	Woodland	level 1	Comprised of open stands of trees more than 5 meters tall with crowns not touching. Greater than 40% of the ground is covered by the tree canopy. Definitions for Mainly Evergreen Woodland, Mainly Deciduous Woodland, and Extremely Xeromorphic Woodland are similar to forest definitions with sparser stocking of individual trees.
11	Mainly Evergreen Woodland	level 2	The canopy is never withoug green foliage. At least 50% of the trees that reach the canopy are evergreen. Individual trees may shed their leaves.
111	Evergreen Broad-leaved Woodland	level 3	Mainly sclerophyllous trees and shrubs, with no epiphytes.
112	Evergreen Needle-leaved Woodland	level 3	Trees are mainly needle- or scale-leaved (more than 50% of the canopy). Crowns of many trees extend to the base of the stem or are very branchy.
1121	Rounded crowns	level 4	E.g., *Pinus*.
1122	Conical crowns prevailing	level 4	Usually in subalpine areas.
1123	Narrow cylindrical crowns	level 4	E.g., *Picea* in the boreal regions.
12	Mainly Deciduous Woodland	level 2	The majority of trees (more than 50% of the canopy) shed their foliage simultaneously in connection with the unfavorable season (drought or cold).
121	Drought-deciduous	level 3	The unfavorable season is mainly characterized by drought, in most cases winter-drought. Foliage is shed regularly every year. Most trees have relatively thick, fissured bark.
1211	Broad-leaved lowland and submontane	level 4	Practically no evergreen plants in any stratum, except some succulents. Woody and herbaceous vines and deciduous bottle-trees are present. Sparse herbaceous vegetation present in the undergrowth.
1212	Montane and cloud woodland	level 4	Some evergreen species are present in the understory. Drought resistant epiphytes are present or abundant, often in the bearded form (e.g., *Usnea* or *Tillandsia usneoides*). This formation is not frequent, but well developed, e.g., in northern Peru.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
122	Cold-deciduous with Evergreens	level 3	The unfavorable season is mainly characterized by winter frost. Deciduous broad-leaved trees are dominant (more than 50% of the canopy), but evergreen species are present (more than 25% of the canopy) as part of the main canopy or the understory. Climbers and vascular epiphytes are scarce or absent.
1221	With evergreen broad-leaved trees and climbers	level 4	Rich in epiphytes and mosses. Vascular epiphytes may be present at the base of tree stems. Climbing vines may be common on flood plains. *Ilex aquifolium* and *Hedera helix* in western Europe and Magnolia spp. in North America are examples of this class type.
1222	With evergreen needle-leaved trees	level 4	E.g., the maple-hemlock or oak-pine forests of Northeastern, U.S.A.
123	Cold-deciduous without Evergreens	level 3	Deciduous trees are absolutely dominant (more than 75% of the canopy). Evergreen herbs and some evergreen shrubs (less than 2 meters tall) may be present. Climbers insignificant but may be common on flood plains; vascular epiphytes are absent (except occasionally at the lower base of the tree); mosses, liverworts and particularly lichens are always present. Cold-deciduous species are absolutely dominant (more than 75% of the canopy). Most frequent in the subarctic region, elsewhere only on swamps or bogs.
1231	Broad-leaved deciduous	level 4	Broad-leaved deciduous species are absolutely dominant (more than 75% of the canopy).
1232	Needle-leaved deciduous	level 4	Needle-leaved deciduous species are absolutely dominant (more than 75% of the canopy).
1233	Mixed deciduous	level 4	Both broad-leaved and needle leaved deciduous species provide more than 25% of the canopy.
13	Extremely Xeromorphic Woodland	level 2	Stands of trees and shrubs adapted to dry conditions, such as bottle trees, tuft trees with succulent leaves and stem succulents. Undergrowth has shrubs adapted to dry conditions, succulent perennial herbs and annual and pernnial herbaceous plants. Woodlands may grade into forest.
131	Sclerophyllous-dominated Extremely Xeromorphic	level 3	Vegetation is similar to Xeromorphic woodlands, with predominance of sclerophyllous trees, many of which have bulbose stem bases largely embedded in the soil.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
132	Thorn Woodland	level 3	Species with thorms are dominant (more than 50% of the canopy).
1321	Mixed deciduous-evergreen	level 4	Both deciduous species and evergreen species are more than 25% of the shrub canopy. See definitions of Mainly Evergreen Forest, class 01 and Deciduous, class 02.
1322	Purely deciduous	level 4	Deciduous thorn species are absolutely dominant (more than 75% of the canopy). See definition of Deciduous Forest, class 02.
133	Mainly Succulent Woodland	level 3	Tree-formed (scapose) and shrub-formed (caespitose) succulents are very f requent (more than 50% of the canopy), but other trees and shrubs adapted to dry conditions are usually present as well.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
2	Shrublands or Thickets	level 1	The shrub canopy covers at least 40% of the ground and is composed of matted, clumped or clustered woody plants 0.5 to 5 meters tall. Shrubland: most of the individual shrubs are not touching each other; often with grass growing between shrubs. Thicket: individual shrubs are interlocked. Shrublands are also further defined (like Forests and Woodlands) as Evergreen Broad-leaved, Evergreen Needle-leaved, Mainly Deciduous, etc. Shrubland: most of the individual shrubs are not touching each other; often with grass growing between shrubs.
21	Mainly Evergreen Shrubland	level 2	The canopy is never without green foliage. At least 50% of the shrubs that reach the canopy are evergreen. Individual shrubs may shed their leaves.
211	Evergreen Broad-leaved	level 3	Evergreen broad-leaved species are dominant (more than 50% of the canopy).
2111	Low bamboo thicket	level 4	Occasionally bamboo forms a shrubland. See class 2 for shrubland and thicket definitions.
2112	Evergreen tuft-tree	level 4	Composed of small trees and woody shrubs, e.g., Mediterranean dwarf palm shrubland or Hawaiian tree fern thicket or shrubland.
2113	Broad-leaved hemi-sclerophyllous	level 4	Matted or clumped shrubs and plants with large soft leaves, e.g., subalpine *Rhododendron* thickets, or *Hibiscus tiliaceus* matted thicket of Hawaii.
2114	Broad-leaved sclerophyllous	level 4	E.g., chapparal or macchia.
2115	Suffruticose thicket	level 4	E.g., *Cistus* heath.
212	Evergreen Needle-leaved and Microphyllous	level 3	Dominant species (more than 50% of the canopy) have either needle leaves or small leaves.
2121	Evergreen needle-leaved	level 4	Composed of creeping or lodged needle-leaved shrubs, e.g., *Pinus mughus*, " Krummholz" .
2122	Evergreen microphyllous	level 4	Evergreen species have small leaves, e.g., desert plants, or leaves with a single unbranched vein.
22	Mainly Deciduous	level 2	The majority of shrubs (more than 50% of the canopy) shed their folidage simultaneously in connection with the unfavorable season (cold or drought).

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
221	Drought-deciduous Mixed with Evergreen Woody Plants	level 3	Drought-deciduous shrubs are dominant (greater than 50% of the canopy) and are mixed with greater than 25% evergreen woody plants.
222	Drought-deciduous without Evergreens	level 3	Drought-deciduous shrubs are absolutely dominant (more than 75% of the canopy).
223	Cold-deciduous	level 3	The unfavorable season is mainly lcharacterized by winter frost. Deciduous shrubs are dominant (more than 50% of the canopy).
2231	Temperate deciduous	level 4	Composed of dense scrub without, or with very little, herbaceous undergrowth.
2232	Subalpine or subpolar	level 4	Composed of upright or lodged matted shrubs with great vegetative regeneration capacity and usually covered by snow for at least half a year.
23	Extremely Xeromorphic (subdesert) Shrubland	level 2	Very open stands of shrubs with various adaptations to dry conditions, such as: extremely thickened, hardened foliage; very reduced leaves; green branches without leaves; or succulent stems, some of them with thorns.
231	Mainly Evergreen	level 3	The canopy is never without green foliage. At least 50% of the shrubs that reach the canopy are evergreen. In extremely dry years some leaves and shoot portions may be shed.
2311	Evergreen subdesert	level 4	Composed of broad-leaved mostly sclerophyllous shrubs, e.g., mulga scrub in Australia, leafless green-stemmed plants, e.g., *Retama retam*, or succulents.
2312	Semi-deciduous	level 4	May consist of either facultatively deciduous shrubs or a combination of evergreen and deciduous shrubs (e.g., evergreen shrubs are dominant, deciduous shrubs cover more than 25%).
232	Deciduous Subdesert Shrubland	level 3	See class 02, Mainly Deciduous Forest.
2321	Without succulents	level 4	Succulents cover less than 25% of the ground.
2322	With succulents	level 4	Succulents cover more than 25% of the ground.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
3	Dwarf-shrublands	level 1	Shrubs rarely exceed 50 cm in height (sometimes called heaths or heathlike formations). The shrub canopy covers more than 40% of the ground. Dwarf-shrub classes are distinguished by the cover density. Dwarf-shrub thicket: branches are interlocked; Dwarf-shrubland: individual dwarf-shrubs are isolated or in clumps; Dwarf-shrublands with surface densely covered with mosses or lichens; dwarf-shrubs occurring in small clumps or individually.
31	Mainly Evergreen	level 2	The canopy is never without green foliage. At least 50% of the shrubs that reach the canopy are evergreen. Individual shrubs may shed their leaves.
311	Evergreen Dwarf-shrub Thicket	level 3	Composed of densely closed dwarf-shrub cover which dominates the landscape.
3111	Caespitose thicket	level 4	Shrub branches stand upright and often hold lichens. Cushion-shaped mosses, lichens and other herbaceous plants are often found on the ground, e.g.,s heath.
3112	Creeping or matted thicket	level 4	Shrub branches creep along the ground, e.g., *Loiseleuria* heath.
312	Evergreen Dwarf-shrubland	level 3	Open or more loose cover of dwarf-shrubs. Shrub canopies are not interlocked. Herbaceous vegetation covers less than 25% of the ground.
3121	Evergreen cushion	level 4	Shrubs are isolated in clumps forming dense cushions and are often thorny, e.g., Astragalus- and Acantholimon " porcupine" -heath of the East Mediterranean mountains.
313	Mixed Evergreen and Herbaceous Formation	level 3	Shrub canopies are not interlocked. Evergreen shrubs are mixed with herbaceous vegetation (more than 25% of the ground).
3131	True evergreen and herbaceous mixed	level 4	E.g., *Nardus Calluna*-heath.
3132	Partial evergreen and herbaceous mixed	level 4	Many individuals shed parts of their shoot systems during the dry season, e.g., *Phyrgana* in Greece.
32	Mainly Deciduous	level 2	The majority of shrubs (more than 50% of the canopy) shed their folidage simultaneously in connection with the unfavorable season (cold or drought).
321	Facultative Drought Deciduous	level 3	Dwarf-shrubs shed their foliage only in extremely dry years.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
322	Obligate Drought Deciduous	level 3	Densely closed dwarf-shrubs lose all or at least part of their leaves in the dry season.
3221	Drought deciduous caespitose	level 4	Shrub branches stand upright and often hold lichens. Cushion-shaped mosses, lichens and other herbaceous plants are often found on the ground, e.g.,*Calluna* heath.
3222	Drought-deciduous creeping or matted	level 4	Shrub branches creep along the ground. e.g., *Loiseleuria* heath.
3223	Drought-deciduous cushion	level 4	Shrubs are isolated in clumps forming dense cushions and are often thorny, e.g., *Astragalus*- and *Acantholimon* " porcupine" -heath of the East Mediterranean mountains.
3224	Drought-deciduous mixed	level 4	Deciduous and evergreen dwarf-shrubs, caespitose herbaceous plants, succulent perennial herbs, and other life forms intermixed.
323	Cold-deciduous	level 3	Densely closed dwarf-shrubs shed foliage at the beginning of a cold season. Richer in mosses and ferns than the drought-deciduous dwarf-shrub class (322).
3231	Drought-deciduous caespitose	level 4	Deciduous and evergreen dwarf-shrubs, caespitose herbaceous plants, succulent perennial herbs, and other life forms intermixed.
3232	Drought-deciduous creeping or matted	level 4	Shrub branches creep along the ground.
3233	Drought-deciduous cushion	level 4	Shrubs are isolated in clumps forming dense cushions and are often thorny.
3234	Drought-deciduous mixed	level 4	Deciduous and evergreen dwarf-shrubs, caespitose herbaceous plants, succulent perennial herbs, and other life forms intermixed.
33	Extremely Xeromorphic Dwarf-shrubland	level 3	Composed of open formations of dwarf-shrubs, succulents, and herbaceous plants adapted to survive or to avoid a long dry season. Mostly subdesertic. See class 23.
331	Mainly Evergreen	level 3	The canopy is never without green foliage. At least 50% of the shrubs that reach the canopy are evergreen. In extremely dry years some leaves and shoot portions may be shed.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
3311	Evergreen subdesert	level 4	Composed of broad-leaved mostly sclerophyllous shrubs, leafless green-stemmed plants, or succulents.
3312	Semi-deciduous	level 4	May consist of either facultatively deciduous shrubs or a combination of evergreen and deciduous shrubs (e.g., evergreen shrubs are dominant, deciduous shubs cover more than 25%).
332	Deciduous Subdesert	level 3	The majority of shrubs (more than 50% of the canopy) shed their folidage simultaneously in connection with the unfavorable season (cold or drought).
3321	Without succulents	level 4	Succulents cover less than 25% of the ground.
3322	With succulents	level 4	Succulents cover more than 25 of the ground.
34	Tundra	level 2	Slowly growing, low formations, consisting mainly of dwarf-shrubs, graminoids, mosses, liverworts and lichens, found beyond the subpolar tree line. Often showing plant patterns caused by freezing movements of the soil. Except in boreal regions, dwarf-shrub formations above the mountain tree line should not be called tundra, because they are as a rule richer in dwarf- shrubs and grasses, and grow taller due to the greater radiation in lower latitudes.
	Tundra, Mainly Bryophyte	level 3	Dominated by mats or small cushions of mosses (more than 50% of the vegetative cover). Groups of dwarf-shrubs are as a rule scattered irregularly and are not very dense. The general aspect is more or less dark green, olive green or brownish.
3411	Caespitose dwarf-shrub/moss tundra	level 4	Clumped or clustered dwarf shrubs are present.
3412	Creeping or matted dwarf-shrub/moss tundra	level 4	Creeping or matted dwarf-shrubs are present.
342	Tundra, Mainly Lichen	level 3	Mats of lichens dominating (more than 50% of the vegetative cover), giving the formation a more or less pronounced gray aspect. Mostly evergreen, creeping or cushion-shaped dwarf-shrubs are present.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
4	Herbaceous Vegetation	level 1	Dominated by herbaceous grasses and grass-like plants such as sedges (Carex), rushes (*Juncus*), cattails (*Typha*) and broad-leaved plants such as clover, sunflowers (Helianthus), ferns and milkweeds (*Asclepias*). Total ground coverage must be greater than 60% herbaceous vegetation.
41	Tall Graminoid Vegetation (Tall Grasslands)	level 2	Plant community consists of dominant grasses over 2 meters tall when flowering or mature (more than 50% of the herbaceous vegetation). Forbs may be present but comprise less than 50% of herbaceous vegetation.
411	With Trees Covering 10-40%	level 3	May be with or without shrubs. This is somewhat like a very open woodland with a more or less continuous ground cover (over 60%) of tall graminoids.
4111	Trees: broad-leaved evergreen	level 4	Broad-leaved evergreen species are greater than 50% of the tree canopy.
4112	Trees: broad-leaved semi-evergreen	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4113	Trees: broad-leaved deciduous	level 4	Similar to class 4112, but seasonally flooded, e.g., in northeast Bolivia.
412	Tall Grass Lands with Trees Covering Less than 10%	level 3	Grassland with trees covering less than 10% of the ground, with or without shrubs.
4120	Trees: needle-leaved evergreen	level 4	Needle-leaved evergreen species are greater than 50% of the tree canopy.
4121	Trees: broad-leaved evergreen	level 4	Broad-leaved evergreen species are greater than 50% of the tree canopy.
4122	Trees: broad-leaved semi-evergreen	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4123	Trees: broad-leaved deciduous	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4124	Tropical/subtropical, trees/shrubs in tufts on termite nests	level 4	Also called termite savannah.
413	Tall Grasslands with Shrubs	level 3	The shrub canopy must cover more than 25% of the ground.

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MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
4131	Shrubs: broad-leaved evergreen	level 4	Broad-leaved evergreen species are greater than 50% of the shrub canopy
4132	Shrubs: broad-leaved semi-evergreen	level 4	Shrubs present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4133	Shrubs: broad-leaved deciduous	level 4	Shrubs present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees. The area is seasonally flooded.
4134	Tropical or subtropical, trees and shrubs in tufts on termite nests	level 4	Also called termite savannah.
414	Tall Grasslands with Tuft Plants	level 3	The canopy of the tuft plants (usually palms)must cover more than 25% of the ground.
4141	Tropical Grasslands with Palms	level 4	E.g., the palm savannas of Arocomia totai and Attalea princeps north of Santa Cruz de la Sierra, Bolivia.
415	Tall Grasslands without Woody Synusia	level 3	Grasslands without trees or shrubs.
4151	Tropical Grassland	level 4	Often seasonally flooded, e.g., Compos de Varzea of the lower Amazon Valley, low latitude regions of Africa, papyrus swamps of the upper Nile Valley,.
42	Medium Tall Graminoid	level 2	The dominant grasses are 50 cm to 2 m tall when flowering or mature (greater than 50% of the herbaceous vegetation). Forbs may be present but comprise less than 50% of the herbaceous vegetation.
4210	Trees: needle-leaved evergreen	level 4	Needle-leaved evergreen species are greater than 50% of the tree canopy.
4211	Trees: broad-leaved evergreen	level 4	Broad-leaved evergreen species are greater than 50% of the tree canopy.
4212	Trees: broad-leaved semi-evergreen	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4213	Trees: broad-leaved deciduous	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
422	**Medium Tall Grass Lands with Trees Covering Less than 10%**	level 3	Grassland with trees covering less than 10% of the ground, with or without shrubs.
4220	Trees: needle-leaved evergreen	level 4	Needle-leaved evergreen species are greater than 50% of the tree canopy.
4221	Trees: broad-leaved evergreen	level 4	Broad-leaved evergreen species are greater than 50% of the tree canopy.
4222	Trees: broad-leaved semi-evergreen	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4223	Trees: broad-leaved deciduous	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4224	Tropical/subtropical, trees/shrubs in tufts on termite nests	level 4	Also called termite savannah.
423	Medium Tall Grasslands with Shrubs	level 3	The shrub canopy must cover more than 25% of the ground.
4230	Shrubs: needle-leaved evergreen	level 4	Needle-leaved evergreen species are greater than 50% of the shrub canopy.
4231	Shrubs: broad-leaved evergreen	level 4	Broad-leaved evergreen species are greater than 50% of the shrub canopy.
4232	Shrubs: broad-leaved semi-evergreen	level 4	Shrubs present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4233	Shrubs: broad-leaved deciduous	level 4	Shrubs present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees. The area is seasonally flooded.
4234	Tropical or subtropical, trees and shrubs in tufts on termite nests	level 4	Also called termite savannah.
4235	Woody synusia of deciduous thorny shrubs	level 4	E.g., the tropical thorn bush savannah of the Sahel region in Africa with Acacia tortilis, A. senegal and other species.
424	Open Synusia of Tuft Plants	level 3	The canopy of the tuft plants (usually palms)must cover more than 25% of the ground.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
4241	Subtropical open palm groves	level 4	E.g., Corrientes, Argentina. Some areas are seasonally flooded, e.g., Mauritia palm groves in the Colombian and Venezuelan llanos.
425	Medium Tall Grasslands without Woody Synusia	level 3	Medium tall grasslands without trees or shrubs.
4251	Mainly sod grasses	level 4	Perennial, much branched creeping grass which binds the sand or soils with its root system. E.g., St. Augustine grass (Stenotaphrum secundatum), the tall-grass prairie in eastern Kansas, or the sandy soil or dunes, e.g., communities of Andropogon hallii in the Nebraska Sand Hills. In some locations the grassland is wet or flooded most of the year, e.g., Typha swamps. If that is the case classify as a wetland. See class 6.
4252	Mainly bunch grasses	level 4	Grasses which chiefly grow in tufts forming an irregular, textured surface. E.g., the hard tussock (*Festuca novae-zelandiae*) grasslands in New Zealand.
43	Short Graminoid	level 1	The dominant grasses are less than 50 cm tall when flowering or mature (more than 50 of the herbaceous vegetation). Forbs may be present but they less than 50% of the herbaceous vegetation.
431	With Trees Covering 10-40%	level 3	May be with or without shrubs. This is somewhat like a very open woodland with a more or less continuous ground cover (over 60%) of short graminoids.
4310	Trees: needle-leaved evergreen	level 4	Needle-leaved evergreen species are greater than 50% of the tree canopy.
4311	Trees: broad-leaved evergreen	level 4	Broad-leaved evergreen species are greater than 50% of the tree canopy.
4312	Trees: broad-leaved semi-evergreen	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4313	Trees: broad-leaved deciduous	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
432	Short Grass Lands with Trees Covering Less than 10%	level 3	Grassland with trees covering less than 10% of the ground, with or without shrubs.
4320	Trees: needle-leaved evergreen	level 4	Needle-leaved evergreen species are greater than 50% of the tree canopy.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
4321	Trees: broad-leaved evergreen	level 4	Broad-leaved evergreen species are greater than 50% of the tree canopy.
4322	Trees: broad-leaved semi-evergreen	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4323	Trees: broad-leaved deciduous	level 4	Trees present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4324	Tropical/subtropical, trees/shrubs in tufts on termite nests	level 4	Also called termite savannah.
433	Short Grasslands with Shrubs	level 3	The shrub canopy must cover more than 25% of the ground.
4330	Shrubs: needle-leaved evergreen	level 4	Needle-leaved evergreen species are greater than 50% of the shrub canopy.
4331	Shrubs: broad-leaved evergreen	level 4	Broad-leaved evergreen species are greater than 50% of the shrub canopy.
4332	Shrubs: broad-leaved semi-evergreen	level 4	Shrubs present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees.
4333	Shrubs: broad-leaved deciduous	level 4	Shrubs present are at least 25% each of broad-leaved evergreen and broad-leaved deciduous trees. The area is seasonally flooded.
4334	Tropical or subtropical, trees and shrubs in tufts on termite nests	level 4	Also called termite savannah.
4335	Woody synusia of deciduous thorny shrubs	level 4	The dominant grasses are less than 50 cm tall when flowering or mature (more than 50 of the herbaceous vegetation). The canopy of deciduous thorny shrubs must cover more than 25% of the ground.
434	Short Grasslands with Tuft Plants	level 3	The canopy of the tuft plants (usually palms)must cover more than 25% of the ground.
4341	Open Synusia of Tuft Plants, subtropical with open palm groves	level 4	The dominant grasses are less than 50 cm tall when flowering or mature (more than 50 of the herbaceous vegetation). The canopy of palms must cover more than 25% of the ground.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
435	Mainly Bunch Grasses with Woody Synusia	level 3	Grasses which grow in tufts, with woody plants interspersed.
4351	Tropical alpine with tuft plants	level 4	This grassland often contains Espeletia, Lobelia, Senecio and microphyllous dwarf-shrubs and cushion plants, often with woolly leaves. Above the timberline in low latitudes: Paramo and related vegetation types without snow in the alpine regions of Kenya, Colombia, Venezuela, etc.
4352	Tropical alpine, very open, without tuft plants	level 4	In these grasslands there is frequent nocturnal snowfall (though the snow is gone by 9 a.m.), the Super-Paramo (i.e. above Paramo) of J. Cuatrescasas.
4353	Tropical or subtropical alpine bunch grass, with open stands of evergreen	level 4	This grassland may also have deciduous shrubs and dwarf shrubs, e.g., Puna south of Oruro, Bolivia.
4354	Bunch grass with dwarf shrubs	level 4	Cushion plants may also grow in this grassland , e.g., Puna south of Oruro, Bolivia.
436	Short Grasslands, without Woody Synusia	level 3	Short grasslands without trees or shrubs.
4361	Short-grass communities	level 4	These communities may fluctuate in structure and floristic composition due to greatly fluctuating precipitation of the semi-arid climate, e.g., short-grass (*Bouteloua gracilis* and *Buchloe dactyloides*) prairie of eastern Colorado.
4362	Bunch-grass communities	level 4	E.g., blue tussock (Poa cloensoi) communities of New Zealand, and alpine dry Puna with Festuca orthophylla of northern Chile and southern Bolivia.
437	Short to Medium Tall Mesophytic Communities	level 3	Meadows
4371	Sod grass communities	level 4	The grassland is often rich in forbs, and occur in lower altitudes with a cool, humid climate in North America and Eurasia. Many plants may remain at least partly green during the winter, even below the snow in the higher latitudes.
4372	Alpine, subalpine meadows	level 4	These grasslands are usually moist much of the summer due to melt water, e.g., Olympic Peninsula, Washington, and the Rocky Mountains of Colorado.
44	Forb Vegetation	level 2	The plant community is dominated by broad-leaved herbaceous plants (all plants except grasses) such as clover, sunflowers (Helianthus), ferns, milkweeds (Asclepias). Forbs cover more than 50% of the herbaceous area. Grasses may be present but cover less than 50%.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
441	Tall Forb Communities	level 3	The dominant forb growth forms are more than 1 meter tall when fully developed.
4411	Fern thickets	level 4	Ferns occur sometimes in nearly pure stands, especially in humid climate, e.g., *Pteridium aquilinum*.
4412	Mainly annual forbs	level 4	Annual forbs, which germinate in the beginning and die at the end of each growing season, are the dominant (greater than 50% coverage) form.
442	Low Forb Communities	level 3	These communities are dominated by forbs less than 1 meter tall when fully developed.
4421	Mainly perennial flowering forbs and ferns	level 4	Some part of the plant is alive all year round. E.g., *Celmisia* meadows in New Zealand and the Aleutian forb meadows in Alaska.
4422	Mainly annual forbs	level 4	Annual forbs, which germinate in the beginning and die at the end of each growing season, are the dominant (greater than 50% coverage) form.. There are several types of low annual forbs. *Ephemeral forb communities in tropical and subtropical regions* : Forbs grow with very little precipitation where, from autumn to spring, clouds moisten vegetation and soil, e.g., in the coastal hills of Peru and northern Chile. The dry season aspect is desert-like. *Ephemeral or episodical forb communities of arid regions:* The " flowering desert" consists of mostly fast growing forbs, sometimes concentrated in depressions where water can accumulate in shrub or dwarf shrub formations of arid regions, e.g., the Sonoran Desert.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
5	Barren Land	level 1	Land with less than 40% vegetative cover. Barren land has a limited ability to support life, and is usually made up of thin soil, sand, or rocks.
51	Dry Salt Flats	level 2	Occur on flat floored bottoms of interior desert basins. A high concentration of salts are present due to extensive water evaporation.
52	Sandy Areas	level 2	Accumulations of sand/gravel, i.e., beaches or dunes.
53	Bare Rock	level 2	Exposed bedrock, desert pavement, scarps, talus slides, volcanic material, rock glaciers and other accumulations of rock without vegetative cover.
54	Perennial Snowfields	level 2	Accumulations of snow and ice that did not entirely melt during the previous summer, occurring where the daily average temperature is 32 F (0 C) in the warmest summer months.
55	Glaciers	level 2	Snow compacted into firn and finally to ice under weight of successive annual accumulations. Re-frozen melt water contributes to increasing density of the glacial ice mass. All glaciers exhibit evidence of present or past motions (moraines, crevasses, etc.).
56	Other Barren Cover	level 2	Dirt, gravel, other loose rock, etc.
6	Wetland	level 1	Marshes, swamps, bogs and other types of wetlands which are periodically or constantly saturated during the growing season. This periodic or constant saturation produces soils with special chemical characteristics and vegetation specifically adapted to wet conditions. The area must have greater than 40% vegetative cover to be classified as a wetland.
61	Riverine	level 2	Wetlands adjacent to a fresh water river channel (Riparian wetlands).
62	Palustrine	level 2	Wetlands dominated by trees, shrubs, persistent emergents (plants), mosses, lichens, etc. The wetlands surround water that is less than 1 hectare in size, has no active channel or tide, is less than 2 meters deep, and has low salinity. This water should be included as part of the wetland.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
63	Estuarine	level 2	Wetlands occurring adjacent to a tidal channel, or in and adjacent to the intertidal zone. An estuary is a water passage where the tide meets the current of a stream. Deepwater tidal habitats and adjacent tidal wetlands are usually semi-enclosed by land but have open, partially obstructed, or sporadic access to ocean water (at least occasionally diluted by freshwater runoff from the land).
64	Lacustrine	level 2	Wetlands surrounding open water (i.e., ponds and lakes) that are greater than 1 hectares in size and greater than 2 meters deep.
7	Open Water	level 1	Lakes, ponds, rivers and oceans. The surface of the land is continually submerged by water greater than 2 meters deep and at least one hectare in size; or continually submerged in an actively flowing channel or subtidal zone. Water should cover greater than 60% of the area, if trees and emergent plants and cover greater than 40% of the area, see wetland categories in class 6.
71	Fresh Water	level 2	Lakes, ponds, and rivers with low salinity.
72	Marine	level 2	Open ocean overlying the continental shelf or an actively flowing tidal channel.
8	Cultivated Land	level 1	The ground is covered by greater than 60% non-native cultivated species (e.g., agricultural crops, cultivated short grasses, lawns) and usually can be distinguished by the regular geometric patterns created by the lawns and fields.
81	Agriculture	level 2	Land is used for growing crops, orchards, horticulture, feeding livestock, and other agriculture.
811	Row Crop or Pasture	level 3	Examples include; corn, wheat, cow pastures, fallow fields, cultivated cranberry bogs and rice fields.
812	Orchard or Horticulture	level 3	Examples include; apple orchards, vineyards, tree nurseries.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
813	Confined Livestock Feeding	level 3	These areas are found on large farms and are used for feeding beef cattle, dairy cows (with confined feedlots), hogs and poultry.
814	Other Agriculture	level 3	Examples include; corrals, and breeding and training facilities on horse farms.
82	Non-agriculture	level 2	Land is used for parks, playing fields, cemeteries, and golf courses.
821	Parks and Playing Fields	level 3	Examples include; baseball diamonds, soccer fields, play grounds, and parks.
822	Golf Courses	level 3	
823	Cemeteries	level 3	
824	Other Non-agriculture	level 3	Any other non-agricultural cultivated areas that do not fit into classes 821, 822 or 823 (parks and playing fields, golf courses, or cemetaries).
9	Urban	level 1	Areas developed for residential, commercial, industrial, or transportation uses. Must be greater than 40% urban land cover.
91	Residential	level 2	At least 50% of the urban land cover consists of residential property (i.e., apartments, private dwellings, etc.)
92	Commercial/Industrial	level 2	At least 50% of the urban land cover consists of commercial or industrial property (i.e., businesses, factories, warehouses, etc.)
93	Transportation	level 2	At least 50% of the urban land cover consists of transportation routes (i.e., roads, highways, railroads, airport runways).
94	Other	level 2	At least 50% of the urban land cover consists of devloped areas that do not fit into residential, commercial, or transportation categories.
Misc. Definitions	Boreal		Also called cold temperate zone has a climate with cool wet summers and cold winters lasting more than six months.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
	Bryophyte		Non-flowering plants (mosses & liverworts) characterized by rhizoids rather than true roots.
	Caespitose		Arranged or combined in a thick mat or clumps, having a low stem forming a dense turf or sod, growing in clusters.
	Canopy		Uppermost layer of vegetation detected by satellite sensors.
	% Cover vs. % Species Composition		The level one classification is determined by the overall canopy or ground coverage of the entire area being classified. The level two classification is determined by the percent species composition only of the dominant level one cover type. Level 3 and 4 are more specific combinations of different species and plant communities. Example: An area is comprised of 80% herbaceous vegetation (of that 45% are forbs and 55% are grasses greater than 2 meters tall), and 20% broad-leaved evergreen trees. The classification codes are as follows: MUC level 1: 4-herbaceous vegetation. It is clearly the dominant cover type, since it covers greater than 60% of the area. MUC level 2: 41. The dominant species are grasses greater than 2 meters tall (they comprise more than 50% of the dominant cover type herbaceous vegetation). MUC level 3: 411. Trees cover 20% of the area. MUC level 4: 4111. The trees are a broad-leaved evergreen species.
	Landscaped vegetation		Landscaped yards, playing fields, cemeteries, golf courses and other cultivated vegetated areas should be classified as cultivated land (class 8) if non-native cultivated species is greater than 60% coverage. If the buildings, roads and unnatural structures (bridges, etc.) cover greater than 40% of the land, the area should be classified as urban. If wooded residential neighborhoods have greater than 40% trees covering the ground, the area would be considered forest or woodlands (see classes 0 and 1). If it is difficult to decide upon a cover type, try to determine what would be seen by the satellite. Compare similar areas with the satellite image you receive of your schoolÕs location.
	Cold-deciduous		Plants that shed leaves during the cold season.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
	Deciduous		Vegetation that sheds its leaves at the end of the growing period or in unfavorable conditions.
	Drip tips		Extended slender tips of tropical leaves that allow water to roll of the leaf surface.
	Drought-deciduous		Plants that shed leaves during the dry season.
	Facultative		Organisms able to live and thrive under more than one set of conditions.
	Firn		Snow compacted almost to ice, glacial material.
	Forb		A broad-leaved herbaceous plant such a clover, sunflowers, ferns, and milkweeds.
	Graminoid		Grasses and grass-like plants.
	Herbaceous		Vascular plant rooted in the ground with foliage that dies back annually. The meristem (stem growth tip) is located just above or below the ground.
	Lowland forest Submontane forest Montane forest Subalpine forest		It may be necessary to consult local resources to determine the specific level 4 classification for forest cover. Vegetation will vary depending on both the latitude and the altitude.
	Mesophytic		Growing in, or adapted to, a moderately moist environment.
	Microphyllous		Having small leaves (e.g., desert plants); having leaves with a single unbranched vein.
	Obligate		Organisms restricted to a particular condition of life (that condition is essential for survival).
	Overstory		Uppermost layer of vegetation detected by satellite sensors.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
	Polar		Low precipitation distributed over the entire year. There is a short wet nightless summer and a very long, cold, dark winter.
	Sclerophyllous		Vegetation with thickened hardened foliage that is resistant to water loss (sclerophylly).
	Subpolar		Transitional between the cold temperate zone and the polar zone.
	Subtropical		From the edge of the tropical zone toward the poles, in the region of the descending air masses, which get warmer as they descend and become very dry. Rainfall is very low, and the daytime temperatures are very high because of intense solar radiation. In the winter months, however, the temperature may sink to zero at night as a result of the greater net loss of heat energy in outgoing radiation. This is the hot desert zone.
	Synusia		A layer or stratum of a community. A structural unit of a major ecological community characterized by relative uniformity of life form or of height and usually constituting a particular stratum of that community.
	Temperate		Temperate zones show greater seasonal temperature changes and can be broken down as follows: Warm temperate: scarcely any or no winter, extremely wet especially in summer. Typical temperate: (e.g., central European or coastal northeastern U.S.A) cold, short winters or a winter free of frost and with very cool summers (near the ocean). Arid temperate: large temperature contrasts between summer and winter, and little precipitation. Boreal or cold temperate: cool wet summers and cold winters lasting more than six months.
	Tropical		Lies 40 degrees to the north and south of the equator. A certain seasonal variation in the mean daily temperature is noticeable. Rainfall reaches a maximum in the summer and a dry season in the cool months. The duration of the cool season increases as the distance from the equator becomes greater, and at the same time the annual rainfall decreases.
	Understory		Layer of vegetation that grows beneath the overstory consisting of smaller trees and shrubs.

MUC Code	Glossary of Terms in the Modified Classification Scheme	Class Level	
	Wet		Vegetation or environments capable of withstanding or thriving in the presence of much rain.
	Xeromorphic		Climatic conditions favorable for the development of vegetation that is adapted to, thrives in or tolerates an environment that is poor in available moisture.
	Xerophyte		A plant which is adapted to and thrives in dry conditions.

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International Classification and Mapping of Vegetation. United Nations Educational, Scientific and Cultural Organization. Switzerland: Unesco, 1973.

NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation. J.E. Dobson et al. NOAA Technical Report NMFS 123, 1995.

Glossary

atmosphere

The gaseous component of the Earth system. The mass of air surrounding the Earth.

AVHRR

Advanced Very High Resolution Radiometer. An instrument carried on NOAA polar-orbiting satellites; it observes the Earth's surface in the visible through thermal infrared regions with a pixel size of 1.1 km.

biogeochemical

Refers to the chemical interactions between the living ("bio") and physical ("geo") components of the Earth system, as in biogeochemical cycles of carbon, nitrogen, etc.

biomass

The dry weight of vegetation above a unit area of ground, often reported as grams (dry weight) per square meter.

biome

A major ecological community type (as grassland or desert).

biometrics

The statistical study of biological data.

biometry

The process of making biological measurements

biosphere

The living component of the Earth system, along with the gaseous (atmosphere), liquid (hydrosphere), and solid (geosphere) components.

canopy cover

The amount of canopy foliage above a given portion of ground is the canopy cover. This will determine the amount of sunlight that reaches that portion of ground.

classification

Sorting a group of items into well-defined and distinct subsets according to specific criteria.

clinometer

A clinometer is an instrument for measuring the angle of a change in height or elevation.

criteria

Decision rules that are used to determine into which subset an item is placed during a classification.

densiometer

A device for determining the percentage of canopy closure in a wooded environment.

dichotomous

This is a branching decision tree (decoder) characterized by successive forking into two approximately equal and contradictory divisions, which ultimately leads to only one correct outcome.

difference/error matrix

A graphic method of comparing two data sets for validation.

evapotranspiration

The return of water to the atmosphere by evaporation (from solar energy) and transpiration (plant activity.)

genus (pl. Genera)

This is an inclusive category whose species have more characteristics in common with each other than with species of other genera. Genera, therefore, are collections of closely related species.

geosphere

The solid component of the Earth system; e.g. rocks, soil, etc.

gradient

The rate of change in a measured quantity over space or time.

ground cover
The amount of ground-level vegetation covering a given area. (For the GLOBE program, "ground level" is defined as "below the observer's knees." Ground cover is expressed as a percentage. E.g. 30% ground cover means that, viewed from above, 30% of the ground surface is obscured by ground-level vegetation.

hydrosphere
The liquid component of the Earth system; e.g. oceans, lakes, rivers, etc.

multitemporal
Viewed from more than one point in time.

NOAA
The National Oceanic and Atmospheric Administration.

perennating organs
Parts of plants that live over from one season to another (tubers, rhizomes.)

perturbations
A disturbance in the normal functioning of a system.

phenology
The study of changes over time in an environmental setting.

photointerpretation
The production of a land cover map or identification of specific features by visual inspection of an aerial photo or satellite image.

photosynthetic potential
The maximum amount of biomass that can be produced in an area.

physiological
Characteristic of, or appropriate to, an organism's healthy or normal functioning.

primary productivity
The rate at which organic material is produced by photosynthesis at a given location. Often represented as grams (dry weight) of Carbon per m^2 per year.

senescence
The plant growth phase from full maturity to death that is characterized by a loss in dry weight.

species
This is a group of individual plants/ animals that is fundamentally alike.

TM
Thematic Mapper. Carried aboard the Landsat 4 and 5 satellites, this instrument is designed to study surface features in 7 bands covering the visible through thermal infrared regions with a pixel resolution of 30 m in 6 bands and 120 m in the thermal infrared band.

validation data
Data necessary to assess the accuracy of a land cover map produced by manual or electronic means.

Seasons Investigation

Putting It All Together

GLOBE DATABASE

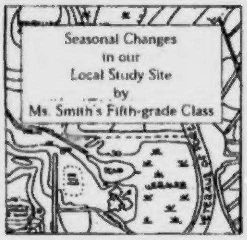
A GLOBE™ Learning Investigation

Seasons Investigation at a Glance

Protocols

No protocols in this investigation

Suggested Sequence of Activities


Seasonal Changes
in our
Local Study Site
by
Ms. Smith's Fifth-grade Class
30
VETERANS

Students read Scientists' letter

Do the Learning Activities:

What Can We Learn About Our Seasons?

What Are Some Factors That Affect Seasonal Patterns?

How Do Seasonal Temperature Patterns Vary Among Different Regions of the World?

What Can We Learn by Sharing Local Seasonal Markers with Other Schools Around the World?

Students design and implement their own investigations in other domains.

Special Notes

This is a set of Learning Activities to help students learn how to do their own science investigations and to integrate the protocols from the other investigations.

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What Can We Learn by Sharing Local Seasonal Markers with Other Schools Around the World? .... Learning Activities-22

Appendix

Pedagogy of the Seasons Investigation Appendix-2
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Mini-Investigation: How Can One Tell Whether Two Parameters Are Interrelated? Appendix-5

Scientists' Letter to Students

Duplicate and distribute to students.

Principal Investigator Dan Barstow expresses the "Wow!" of science education.

Dear Students,

This investigation is a little different from the others. Rather than ask you for new data, you will be able to investigate questions that interest you. In the process of doing your own research, we hope you will learn key science concepts and better understand what science is about.

As you explore your study site, keep track of questions that interest you. Why is the soil wet in one area and dry in another? Why are there so many different types of land cover in your study site? Why do things change so much every season?

Also keep track of questions as you look at data from the other schools around the world. Where are the coldest and warmest places in the world? What is the most common type of land cover reported by schools within 500 miles of your school? What other areas of the world have the same type of land cover? Why?

Principal Investigator Boris Berenfeld

These activities focus on seasons. Seasonal changes directly impact our lives. What are the coldest and warmest days of the year at your site? Are these the same every year? Are they the same all over the world? Can you tell what season it is by looking at a satellite photo of Earth from space? Yet, what makes seasons change is not obvious.

The Seasons investigations provides you with a wonderful opportunity to figure out the answers to your questions by looking at the actual data from other schools. This is how scientists learn – they observe the real world, ask questions, collect data, explore the data, ask more questions, and try to figure out what is going on. You will have a chance to design your own investigations and collaborate with other students all over the world to do your research. Ultimately, you will see how your local community fits into the global environment.

Once you feel comfortable with doing scientific investigations, we hope you will design investigations based on any question that interests you.

Dan Barstow (Principal Investigator)
Boris Berenfeld (Principal Investigator)
Harold McWilliams (Project Director)
Chris Randall (Senior Curriculum Developer)

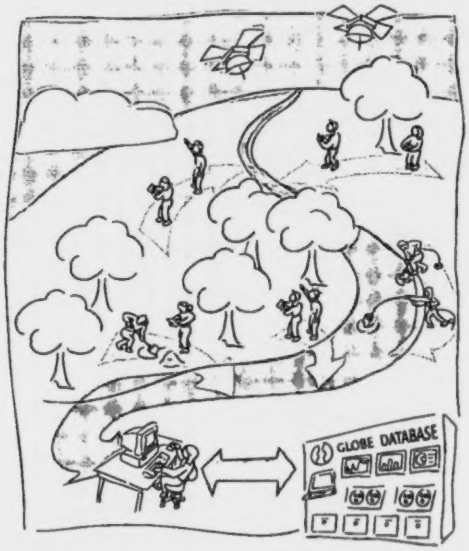
Introduction

The Big Picture

GLOBE student observations of the atmosphere, surface water, soil moisture and temperature, and vegetation all are impacted by seasonal changes as Earth orbits the Sun. These seasonal changes illustrate the interconnectedness among these aspects of our environment. Many important seasonal phenomena and regional differences can be studied based on the environmental and climatic parameters measured in the GLOBE program. Seasonal change is a response to increasing or decreasing levels of solar energy input, and GLOBE measurements are windows into these changing energy levels.

The Seasons investigation integrates science concepts and data from the various protocols. Your students will explore annual planetary changes – seasons – as a focal point for integrative learning. This chapter has two major areas of emphasis:

1. Learning science content – Helping students learn about seasonal cycles and helping them explore the interconnectedness among all aspects of the Earth system



2. Developing investigation skills – Helping students learn how to design and conduct their own GLOBE investigations

The concept of seasons is simple enough for students of all ages to grasp, and yet, it can be investigated at many levels. For K-3 students, the goal of the Seasons chapter is to observe many of the changes that occur throughout the year and to understand their observations and measurements as windows into large-scale, complex changes. For intermediate and advanced students, an additional goal is to understand the factors that underlie the differences in seasonal patterns around the world.

Why Are There Seasons?

Like tides washing regularly across a beach, seasons advance and retreat across the face of the globe and bring changes that transform the face of the Earth. Whether it is the arrival of the winter snows, the monsoon rains, or the summer heat, our environment changes constantly, and these profound changes occur over relatively short time periods. What helps make such huge, complex changes comprehensible is that they reoccur in predictable ways. Many ancient civilizations observed that the Sun's position in the sky changed throughout the year and were able to construct calendars and predict seasonal change based on their observations.

All seasonal changes are driven by changes in the amount of the Sun's energy reaching the Earth's surface (i.e., the amount of *insolation*). For example, more energy leads to higher temperatures which results in more evaporation which produces more rain which starts plants growing. This sequence describes Spring at mid-latitudes. Since visible light is the main form of solar energy reaching Earth, day length is a reasonably accurate way to gauge the level of insolation and has long been used as a way to understand when one season stops and the next one starts. For example, the first day of summer (the *summer solstice*) is the longest day of the year. Winter starts on the shortest day of the year, the *winter solstice*. The first days of fall and spring are when the day and night are of equal length – roughly 12 hours each. These days are named the *vernal* and *autumnal equinoxes*.

Changing day length implies that the Earth's axis of rotation is inclined with respect to the plane of its orbit around the sun. The ancient Greeks knew that the Earth was inclined 23.5° Figure SE-I-1 shows the inclined Earth at different positions in its orbit. Notice how at the solstice positions, each pole is tilted either toward or away from the Sun. The pole inclined toward the Sun receives 24 hours of sunlight, and the one inclined away is in the Earth's shadow and experiences 24 hours of darkness. At the equinox positions, the Earth is inclined in a way so that each pole receives equal amounts of insolation. This discussion focuses on the poles because they experience the greatest extremes of insolation. Because of the inclination of the Earth's axis, insolation levels at every point on Earth change constantly. We call the effects of these changing levels seasons.

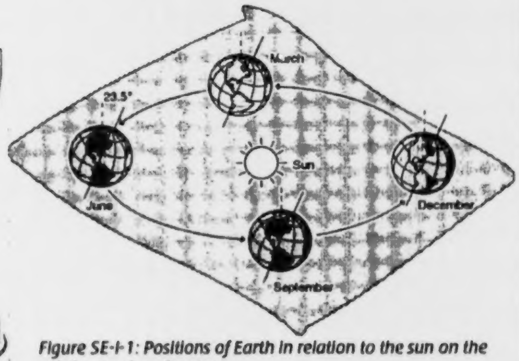


Figure SE-I-1: Positions of Earth in relation to the sun on the solstices and equinoxes

Latitude

Figure SE-I-2 shows how insolation levels vary with latitude. Because of this variation, latitude has a powerful influence in determining seasonal conditions and the annual patterns of environmental and climatic parameters such as precipitation and temperature.

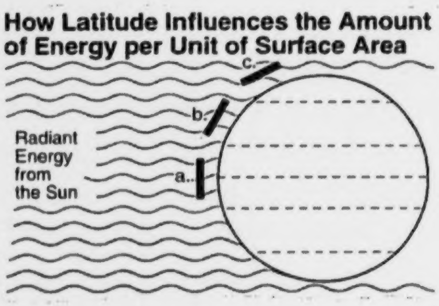

How Latitude Influences the Amount of Energy per Unit of Surface Area
c.
b.
Radiant Energy from the Sun
a.

Figure SE-I-2: Areas a, b, and c are all the same size, yet they all receive different amounts of the sun's "rays."

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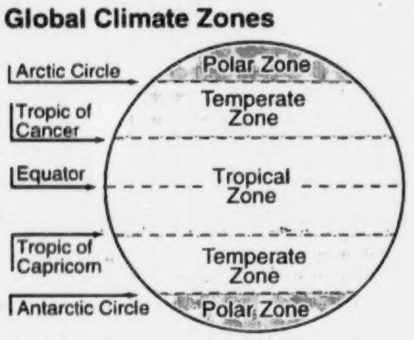
Different Climatic Zones

The same season can be quite different in the *Tropical*, *Temperate* and *Polar* zones. These seasonal differences are based on the duration and directness of insolation. See Figures SE-I-2 and SE-I-3.

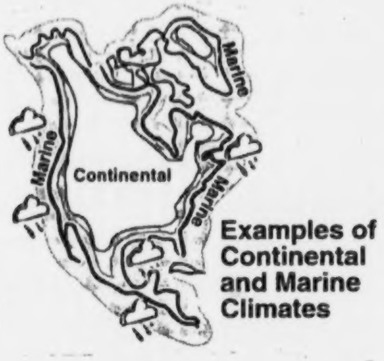
Figure SE-I-3


Global Climate Zones
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
Polar Zone
Temperate Zone
Tropical Zone
Temperate Zone
Polar Zone

Continental and Marine Climates

Marine climates have larger amounts of moisture and smaller temperature changes from summer to winter than continental climates. However, the size of a continent affects both the temperature range and the amount of moisture in the interior – the larger the continent, the larger the effect. See Figure SE-I-4.

Figure SE-I-4


Marine
Marine
Continental
Marine
Examples of Continental and Marine Climates

Two Key Factors That Affect Precipitation Levels

Amount of Water Vapor: Evaporation is how most of the water vapor enters the atmosphere, and air near large bodies of water such as oceans have the highest levels of water vapor. Also, higher temperatures increase evaporation rates. Consequently, air in tropical regions downwind from large sources of water tends to have the highest levels of water vapor, while air in temperate and polar regions in the center of large continents tends to have the driest air. In this example, *geography* influences amount of water vapor that influences precipitation levels.

Temperature: Though evaporation increases as temperatures rise, warm air holds more moisture than cool air. Warm air can cool in several ways. On a local level, the atmosphere cools at night, and the morning dew is the result of the water vapor condensing on cool surfaces. Warm air masses can move to cooler locations. Many storms start as warm, humid air masses that move to higher, cooler altitudes and latitudes. In this example, *latitude* influences temperatures which influence precipitation levels. Finally, increases in elevation cause air to cool. Generally, the atmosphere cools 1°C for every 150 meter rise in elevation. A considerable percentage of the water vapor in air rising over mountains condenses and falls as precipitation. In this example, *elevation* and *geography* influence temperatures which influence precipitation levels.

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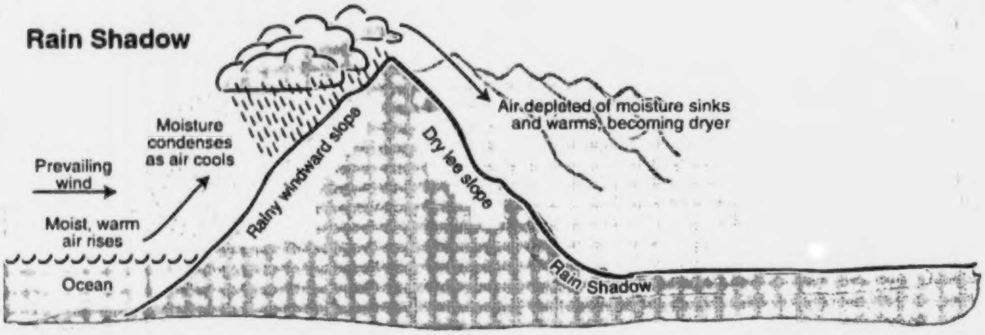
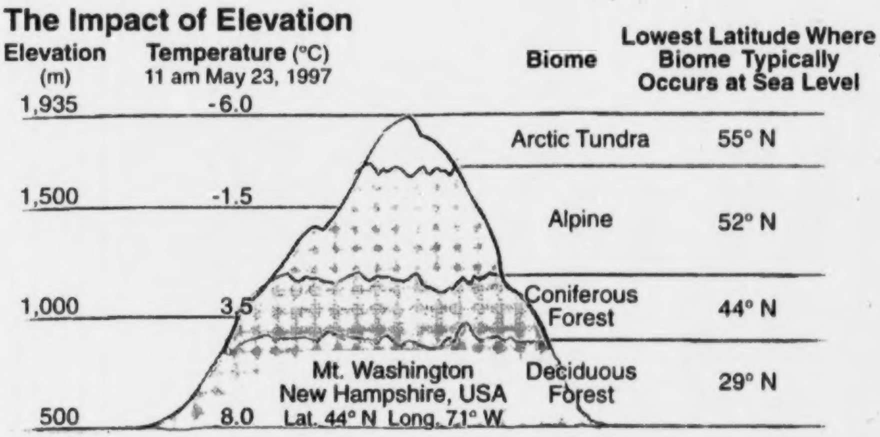
Figure SE-I-5


Rain Shadow
Prevailing wind
Moist, warm air rises
Moisture condenses as air cools
Ocean
Rainy windward slope
Dry lee slope
Air depleted of moisture sinks and warms, becoming dryer
Rain Shadow

Geographical Features

Geographical features have profound impacts on nearby regions. For example, mountain chains can cause moist air to rise and precipitate out almost all of its moisture. When this *desiccated* (depleted of moisture) air descends to the regions behind the mountain chain, it creates a *rain shadow.* See Figure SE-I-5. Many deserts are found in such rain shadows. In addition to arid land, typical desert regions lack the atmospheric moisture that acts as insulation between the Earth's surface and space (water is the major greenhouse gas on Earth). Consequently, desert areas easily radiate their heat energy out to space, and day and night temperature differences are considerable.

Figure SE-I-6: A comparison of elevation, temperature, biome and latitude on Mt. Washington


The Impact of Elevation
Elevation (m)
Temperature (°C) 11 am May 23, 1997
Biome
Lowest Latitude Where Biome Typically Occurs at Sea Level
1,935
-6.0
Arctic Tundra
55° N
1,500
-1.5
Alpine
52° N
1,000
3.5
Coniferous Forest
44° N
500
8.0
Deciduous Forest
29° N
Mt. Washington
New Hampshire, USA
Lat. 44° N Long. 71° W

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Elevation

Changes in elevation can affect the environment as much as changes in latitude. Temperature falls approximately 1°C for every 150 meter increase in elevation, and, in terms of growing season, every 300 m increase in elevation is roughly equivalent to moving toward the nearest pole by 400-500 km (roughly four to five degrees of latitude). Mountain tops can be thought of as climatic islands where, in the Northern Hemisphere, northern species extend their ranges southward onto mountains where conditions resemble those of more northern latitudes. Plants growing on the top of New Hampshire's Mt. Washington (1,935 m) would feel right at home growing at sea level in the Arctic tundra, 2,400 km to the north in Canada. See Figure SE-I-6.

Global Energy Transfer Systems

As illustrated in Figure SE-I-2, the tropics receive more energy from the sun per unit of surface area than temperate or polar zones. In fact, even though the warmer tropics radiate more heat to space than high latitude regions, the tropics receive more energy from the sun than they radiate away! Where does this excess energy go? The circulation of the atmosphere and the oceans carries this energy, in the form of heat, to higher latitudes. See Figure SE-I-7.

If we consider the average north-south motion of the atmosphere, warm air from near the equator rises and moves toward the poles. At roughly 30° latitude, the air cools, falls and moves equatorward near the surface. A similar pattern exists in the polar zones, with air rising at roughly 60° latitude and falling at the poles. Since the tropical and polar zones bracket the temperate zones, the tropical and polar circulations drive the circulation patterns of the temperate zones. As a result, the air in temperate zones moves poleward at low altitudes, rises at roughly 60°, returns equatorward aloft and falls at roughly 30°.

In the oceans, strong currents such as the Gulf Stream, the Brazil, the East Australia, and the Kuroshio carry warm water from the tropics to latitudes of roughly 50°. Less prominent currents also contribute to this heat transport. Consequently, regions at high latitudes adjacent to an ocean, such as Ireland, have climates typically associated with regions at lower latitudes.

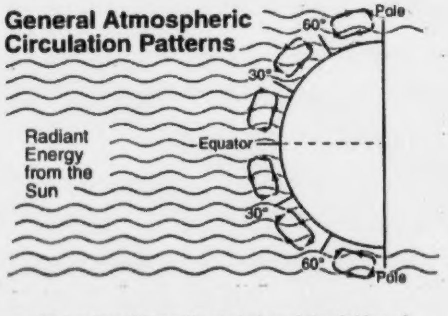
General Atmospheric Circulation Patterns
60°
Pole
30°
Radiant Energy from the Sun
Equator
30°
60°
Pole

Figure SE-I-7: The rising of heated air and the sinking of cooled air drives atmospheric convection cells.

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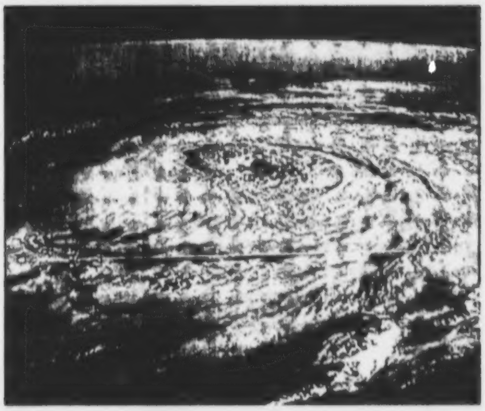


How Are Components of the Earth System Impacted by Seasonal Changes?

The atmosphere is perhaps the most obvious in its seasonal changes. There are annual cycles in temperature and precipitation. Hurricanes and tropical storms are season-dependent, as are droughts and monsoons. Storm systems result from large-scale movements of air masses that are strongly affected by seasonal changes.

Earth's ecology has adapted to Earth's seasonal changes in some remarkable ways. Animals migrate during the year to avoid extreme conditions. Most species have annual reproductive cycles. Plants have their highest photosynthesis levels in the summer when the sun is highest, and then some drop their leaves so that they do not drain their energy resources during the winter. Seeds germinate when soil temperature and moisture are favorable.

Soil conditions vary seasonally. For example, seasonal biological changes such as leaves falling enrich the soil. Soil conditions also vary seasonally as a result of changes in precipitation patterns, and your students might find differences in the rate at which rain soaks into the ground at different seasons.

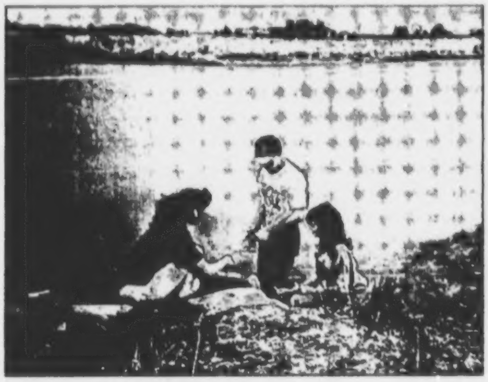
The hydrologic cycle shows seasonal changes in all aspects of the water cycle. Rainy and dry seasons affect the quantity and quality of water in rivers and lakes. Catastrophic flooding can occur in spring as winter snows melt. Seasonal monsoons are essential for the replenishment of water reserves in many parts of the world.

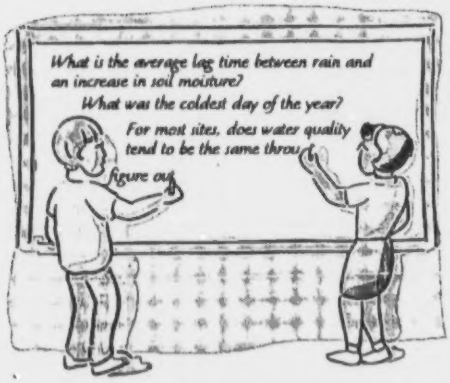
Students' Own Investigations Teach Research Skills

This chapter is a set of integrated student activities. Within the broad domain of seasons, students ask questions, speculate about ideas, observe their study sites, collect and analyze data, communicate with other students and scientists, use multiple sources of information, and communicate their findings.

By doing such investigations, students learn how to do scientific research. In addition, this hands-on, inquiry-based approach is also a powerful way for students to learn science content. By designing and implementing their own investigations, students engage in multidimensional learning that is far more effective than reading science in textbooks.

In these activities we emphasize the analysis of local as well as global data. The best investigations emerge from the questions that the students themselves ask as they observe their study sites and explore the GLOBE database. Be alert for questions that can serve as springboards for investigations. As questions come up, have students record them in their GLOBE Science Notebooks.




What is the average lag time between rain and an increase in soil moisture?
What was the coldest day of the year?
For most sites, does water quality tend to be the same throu
figure ou

An Overview of Student Assessment in the Seasons Investigation

Since student investigations are a major focus of the Seasons Investigation, your evaluation should emphasize assessing the quality of their investigations. While specific assessment questions are listed at the end of each activity, we suggest that you evaluate your students' progress at three stages of their investigations:

1. In the early stages, what kinds of questions are they asking?
Your students should demonstrate a questioning attitude as they observe their study site and look at the GLOBE data. Their questions should show genuine personal curiosity and be based on a novice's understanding of the science domain. As the students select questions for further investigation, they should have a reasonable chance of finding answers with further observations of the study site or deeper analysis of GLOBE data.

2. In the middle stages, are they able to make sense of the data?
This stage emphasizes the use of study site observations and GLOBE data. For younger students, do they observe carefully, record their observations accurately and find patterns in their observations? For older students, do they understand the measurements on which the GLOBE data are based, are they able to use graphs and maps to analyze the data, and do their analyses make sense?

3. In the later stages, are they able to communicate findings to others?
When they complete their investigations, students need to be able to share their findings with you, their classmates, GLOBE scientists, and students throughout the world, and the general public. Whether their communications are in written or verbal form, do the students demonstrate a clear understanding of their investigations? Do they understand the underlying systems they are investigating and the relationships within such systems? Are they able to communicate clearly to their audience? Does the investigation itself show the depth and quality that you expect from a student at this level?

We also encourage you to assess students' understanding of content and interconnections. Students could, for example, construct concept maps (if this is a device you use) or reports or displays that explain the systems and causal connections that they've been investigating.

Implementation Recommendations

1. Do at least one learning activity from another protocol.
The Seasons Investigation is best implemented after your students have begun exploring their study sites and begun collecting and submitting data for at least one of the protocols. It is even better if you have data from additional protocols, either from your own class or from other collaborating classes in your school or district.

2. Accumulate data over the full year.
Exploring seasonal changes requires having enough data for your students to begin to identify changes over the course of the full year. This underscores the importance of beginning your measurements early in the year and doing them regularly, as detailed in the protocols. If your school has been in GLOBE less than one year, you can use data from a nearby school or from several weather data bases available in the GLOBE Resource Room. Some of these data bases have data from thousands of stations going back several hundred years, in some cases.

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3. Promote a questioning attitude all the time.
With GLOBE investigations, and in real science research, an important skill is the ability to ask interesting questions. You can make questioning a more important part of your classroom by encouraging students to record their questions in their GLOBE Science Notebooks and by reviewing these questions from time to time.

4. Use the Student Data Server and GLOBE Visualizations
In the Seasons chapter, your students will make use of the GLOBE Student Data Archive and GLOBE Visualizations. The maps, satellite images, visualizations, data base and data analysis tools are extremely powerful resources for your students to pursue their own investigations. The appendix has detailed instructions to help students access and use the data and tools called for in each activity.

Key Concepts and Skills in the Seasons Investigation

Concepts

- Seasonal changes demonstrate the interconnections among the Earth's systems.
- Environmental and climatic parameters follow predictable cycles over the course of a year;
- Environmental and climatic parameters respond to changing levels of insolation, with some responding more dramatically than others;
- Seasonal markers respond directly to the level of environmental and climatic parameters;
- Different regions experience seasons differently, and factors such as latitude, elevation, and geography impact local seasonal patterns.

Skills

- *Graphing* GLOBE data to show seasonal patterns.
- *Comparing* graphs and *analyzing* data.
- *Asking* questions and *developing* hypotheses.
- *Designing* and *implementing* investigations
- *Drawing* conclusions and *communicating* them to others.

Learning Activities

What Can We Learn About Our Seasons?

Students develop a qualitative understanding of the characteristics and patterns of seasons and highlight the relationship of seasons to physical, biological and cultural markers.

What Are Some Factors That Affect Seasonal Patterns?

Students use GLOBE data and graphing tools to compare the influence of latitude, elevation, and geography on seasonal patterns.

How Do Regional Temperature Patterns Vary Among Different Regions of the World?

Students use GLOBE visualizations to display student data on maps and to learn about seasonal changes in regional and global temperature patterns.

What Can We Learn by Sharing Local Seasonal Markers with Other Schools Around the World?

This activity promotes collaborations among teachers during and after the GLOBE teacher training program. It helps teachers and students learn how to work with the GLOBE data system and GLOBEMail email. It also helps teachers and students learn how the protocols are interconnected and can support inquiry-based investigations.

What Can We Learn About Our Seasons?

Purpose

Students develop a qualitative understanding of the characteristics and patterns of seasons and highlight the relationship of seasons to physical, biological and cultural markers.

Overview

Students observe and record seasonal changes in their local study site. They establish that these phenomena follow annual cycles and conclude the activity by creating displays that illustrate the repeating pattern associated with the appearance and disappearance of seasonal markers.

Time

Ongoing

One class period per month to visit the GLOBE study site; one or two additional class periods per month to record, graph, and discuss observations

Note: There is some advantage in designing a schedule for Study Site visits which corresponds to the data collection visits used in the protocols.

Level

All

Adapting the Activity to Different Levels:

Beginning: as described here

Intermediate: Discuss the strengths and weaknesses of qualitative data.

Advanced: Require more detailed observations of seasonal transitions. Also, discuss whether it is a coincidence that many cultural celebrations correlate with the solstices and equinoxes.

Key Concepts

Seasons have distinct characteristics.

Seasonal changes can be observed in our study site.

Seasonal changes follow an annual cycle.

Through careful observation, you can begin to understand seasonal patterns.

Skills

Observing seasonal changes

Recording observations in GLOBE science journals

Organizing observations in tables and graphs

Representing information with pictures, numbers, and photographs

Materials and Tools

Large sheets of paper

Colored markers

Glue

GLOBE Science Notebooks

Prerequisites

None

Background

The purpose of this activity is to engage your students in careful observations of the seasonal changes that occur in their GLOBE study site. Because we want them to be active participants in planning what they will observe, we ask them to predict which things they think will change in the study site. We then ask them to make careful observations and to compare these with their predictions. When they have collected observations over an extended period of time we ask them to identify trends in the phenomena and to predict "what will happen next" and why. In Step 6 we ask them to think about how the changes they observe are interrelated and in Step 7 to relate the observations to the conventional astronomical markers of seasons (solstices and equinoxes). The activity concludes by asking students to create a profile of each local season using their own observations and, if they wish, to share this with another GLOBE school using GLOBEMail.

We envision this as an activity that continues throughout the school year, with students adding observations on a periodic basis. As the teacher, you will need to decide how often students will visit the study site to make observations. If your site is readily accessible, you may be able to visit as often as once a week, especially during times of the year when many things are changing. But if this is not feasible, try to visit the site monthly. These visits can be supplemented by asking students to make observations near the school, looking out the window, at home, and as they travel to and from the school. If you keep separate records of changes observed at different local sites, you can discuss how the different sites compare.

Understanding what causes seasons is not the primary goal of this activity. Rather, it should be viewed as an introductory activity that focuses students on making careful observations, recording these observations in a systematic way, and noticing the annual cycles that their observations reveal. Remember that GLOBE is an international program and that seasonal changes are quite different in different parts of the world where GLOBE schools are located. This is a wonderful asset of the GLOBE program! We suggest that you contact a GLOBE school in another part of the world and share information with them on your seasonal observations.

Procedure

1. Ask students to think about the seasons that occur in their GLOBE study site. How would they characterize the local seasons? How many seasons are there? What are they called? When do they begin and end? Compose a description of local seasons that the class can agree on.

2. Brainstorm about change.

   Ask students to think about things that are likely to change in their GLOBE study site during the course of the year as the seasons change. Organize them in small groups and ask each group to make a list of all the changes they think might take place. One way to do this is to think about how the study site will change during each month of the year. Guide them to think about changes such as:

   - changes in plant life and vegetation, e.g. blossoming of trees and flowers, leaves dropping, grass turning brown, the appearance of certain fruits
   - changes in animal behavior, e.g. birth of babies, hibernation, migration
   - changes in the physical environment, e.g. getting warmer or colder, rainier or drier, freezing or thawing of bodies of water.

   Have a whole-class discussion of all the changes that the small groups have recorded. Create a composite list for the entire class of changes that you think will occur in the study site during the course of a year.

3. Record actual observations.
   The point now is to begin to observe systematically the kinds of changes that students listed in the preceding step. Help students develop an organized system of recording changes that they observe in the study site. If they have GLOBE Science Notebooks, they can record their observations there. But, in addition, they should record the observations in a form that can be displayed and viewed by the entire class for purposes of discussion. Particularly with younger students, the format should be large and easy to understand. One possibility is to use large sheets of chart paper, one paper per observation period. All the observations made during a given week or month can be recorded on a single large sheet of paper. The paper can then be hung in the classroom, attached to a bulletin board, or displayed in the hallway. As the students

make other visits to the study site they can record their observations on separate sheets and add them to the display. The sheets can include sketches, leaves, blossoms, or buds collected (fastened on with glue), photographs the students took, numerical data they might have gathered, and "impressions" they might have recorded in prose or poetry.

4. Review the changes that have been observed in the study site.

   Once the students have made some observations and recorded them, it will be valuable to review them in light of the lists produced in Step 2. Compare the actual observations with the expectations. As you accumulate data over time, discuss how the study site changes from one visit to another. What were the changes in vegetation, the water, the animals that live there, the moisture, the temperature, etc. Refer to the observations made during the previous visit to form comparisons. If the observations have been recorded on large sheets of paper, then it will be easy to refer to them during the discussion. Ask students to talk about what has changed and what has not changed. As a concluding activity, summarize the changes that have been observed. For younger students, the teacher can write down summaries of what the students say; older students might write a summary in their GLOBE Science Notebooks.

5. Predict and explain.

   Ask students to predict, based on what they saw on this visit and the last, what changes they expect in the study site on the next visit. Ask them to think about what is happening in the study site, what is happening with the season. What trends do they see developing? Do they think the temperature will be colder or warmer next time? Will the site be wetter or drier? Will the vegetation be more leafed out or less? Whatever observations they are tracking, ask them to predict what they think the next period's observation will bring. Ask them to explain why they expect the changes they predict. (This will also give you an insight into their reasoning process.) What do they think might be causing the changes they predict? Record these predictions on a large sheet of paper and keep it for comparison with the actual observations next time. You may also want students to record one or more predictions in their GLOBE Science Notebooks.

6. Explore relationships among changes.

   The changes that students are observing in their study site are not occurring in isolation. They are interrelated parts of seasonal change. Ask students to think about and discuss the possible relationships among the phenomena or parameters that are changing. Ask them to discuss, for example, how changes in air temperature are related to changes in animal behavior; how changes in moisture in the ground are related to changes in plants that are growing in the ground. Look for as many relationships as possible. Ask students to explain why they think these phenomena are related to each other. As a class, write down why you think these things are related. Also ask students to write about these relationships in their GLOBE Science Notebooks.

7. Relate the observations to the conventional seasons.

   The summer and winter solstices and the vernal and autumnal equinoxes define the conventional seasons. Explain to students that these are special days in the annual calendar, and that they are marked as the longest and shortest days and the days that have equal amounts of daylight and darkness. Ask students to think about the condition of their study site in relation to these divisions of the year. What changes do they observe that might coincide with these astronomical markers? Using the data they collect, ask students to see where they think each season actually "should" begin and end. Ask them to think about whether there are any easily defined, sharp markers of the beginning and end of each season.

8. Create a profile of your seasons.

   As a culminating activity, ask students, perhaps working in small groups, to create a profile of each local season based on the observations they have made. (This activity may have to wait until you have collected sufficient data.) Ask the students to characterize not only the "height" of a season but also the transition points between seasons. Ask them to think about how the observed phenomena mark the beginning, the height, and the end of each season. Consider whether the seasons begin abruptly or gradually. For example, in monsoon areas, the onset of the first monsoon rain begins suddenly, followed by a more gradual drop in temperature. Consider sharing the profiles you create with another GLOBE school through GLOBEMail.

Assessment

- Ask students to select one aspect of the study site that they have studied, such as trees, and to describe how trees change in the study site over the course of a year. The description could be pictorial, graphical, verbal, or kinesthetic.
- Give students observations of one aspect of the study site (such as the air temperature) from two or three months of the year (such as November and December) and ask them to predict what the observation would be like in the month following and preceding the observed months (October and January). This asks them to be able to identify a trend and its direction.
- Give students the observations from a "mystery month" and ask them to tell what month they think it was and why. If it is too difficult to pinpoint the exact month, ask them to identify the season in which they think the observation was made.

Extensions

- If students are comfortable with graphical representation of data, they can create graphs showing certain study site conditions. Current temperature and precipitation would be particularly appropriate.
- Contact another GLOBE school using GLOBEMail and share your observations with them. Ask them to send you their observations at their study site. Look at their observations and try to predict how their site will change at the next observation. Compare your prediction with what they send you next.
- Investigate how seasons are portrayed in art, literature, and history. How, for example, were the seasons expressed in painting by the French Impressionists? How have seasons affected the outcomes of military battles, such as the siege of Leningrad? How are seasons portrayed in Shakespeare's plays and poetry? How did Thoreau describe the seasons in *Walden*? How are the seasons described in the *Little House on the Prairie* series of books?

What Are Some Factors That Affect Seasonal Patterns?

Purpose

Students use GLOBE data and graphing tools to compare the influence of latitude, elevation, and geography on seasonal patterns.

Overview

Students analyze the graph of the past year's maximum and minimum temperatures at their site. They compare this graph to similar graphs for two other sites - one nearby and one distant. They list factors that might cause the patterns to be different, and select one to investigate in depth. They repeat this process with other parameters. Students summarize their investigations by describing how latitude, geography and elevation influence seasonal patterns.

Time

(assuming 45 minute classes)

Day 1	Steps 1-3
Day 2	Steps 4 and 5
Day 3	Steps 6-9
Days 4 and 5	Steps 10 and 12
Extension	Step 11

Level

Intermediate and Advanced

Key Concepts

Seasonal patterns are influenced by a combination of latitude, elevation and geography.

The annual patterns of the parameters measured in GLOBE are interrelated.

Skills

Graphing GLOBE data to show seasonal patterns

Comparing graphs and *analyzing* data to determine the effects of latitude, elevation and geographical features

Generating questions and *developing* hypotheses

Designing and *conducting* an investigation

Drawing conclusions about which factors can influence seasonal patterns

Communicating conclusions to others

Materials and Tools

Wall map of the world, if computers are unavailable or limited in number, print outs of the graphs in Steps 1, 4 and 6

Computer and the GLOBE Student Server

GLOBE Science Notebooks

Prerequisites

Students should understand that insolation levels vary with latitude, and that latitude has a powerful influence in determining seasonal conditions and the annual patterns of environmental and climatic parameters such as precipitation and temperature. For a more complete discussion, read *Why Are There Seasons?* in the Seasons Introduction.

Procedure

Step 1: Using the GLOBE graphing tool, have students plot the past year's maximum and minimum temperatures for their site on a single graph. See Figure SE-L-1.

Note: If your school is a new GLOBE site with little data, see *Finding a Nearby GLOBE School* or *Finding GLOBE Sites With Many Reported Measurements* in the appendix to find a nearby GLOBE site whose data you can use when you need long-term data for your area. Also, see *Using the GLOBE Graphing Tool* in the *Toolkit*.

Figure SE-L-1: The plot of a GLOBE site's maximum and minimum temperature data generated by the graphing tool

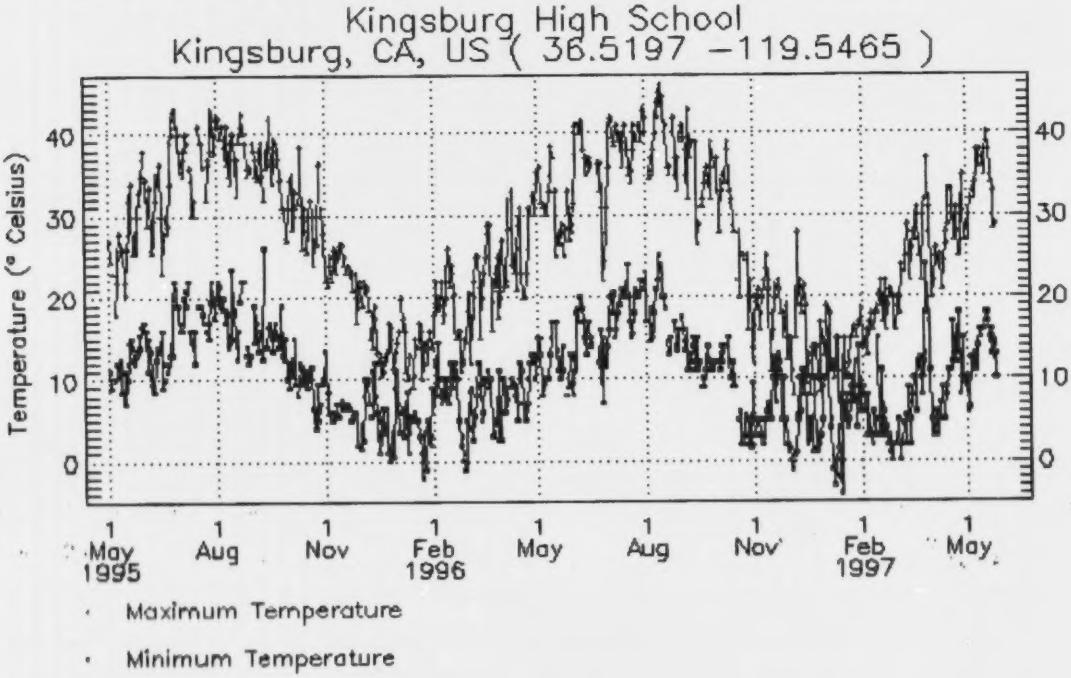
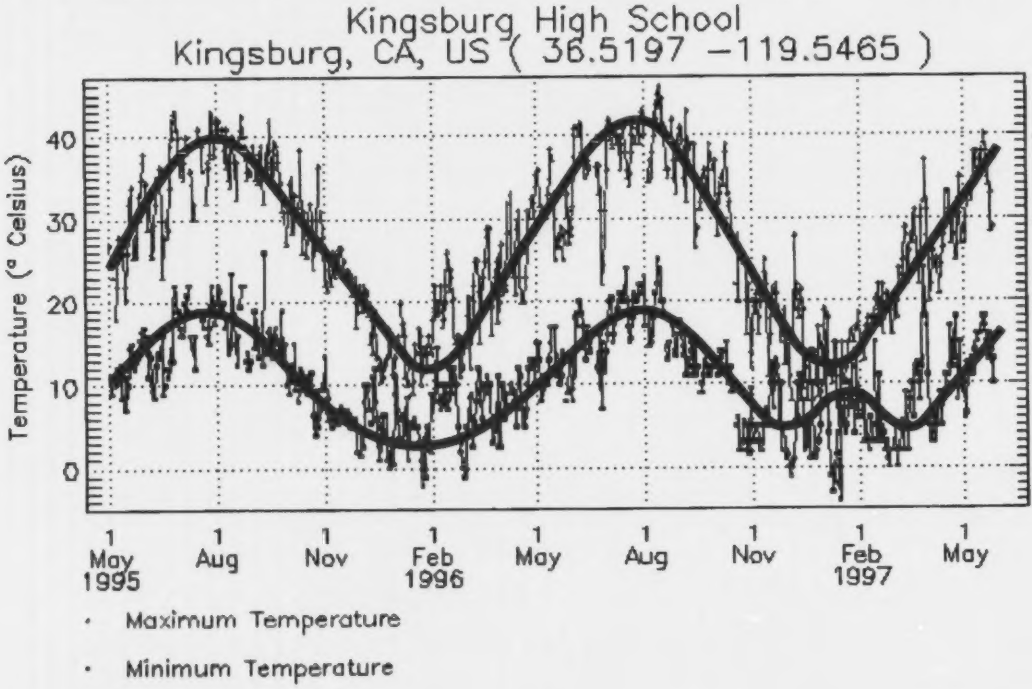


Figure SE-L-2: Two "average lines" drawn through a plot of a GLOBE site's maximum and minimum measurements.



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Step 2: To highlight the general temperature trends, have students use one of the following ways to draw a line through the middle of the plot of the maximum and minimum temperature measurements.

a) have each student draw the lines directly on a copy of the graph.

b) have students lay a clear sheet of acetate over a copy of the graph and draw the lines onto the acetate with overhead markers.

Note: Because temperatures can fluctuate dramatically from day to day, a plot of daily temperatures can look very jagged. Furthermore, since the GLOBE graphing tool connects each data point with a line, the resulting graph has a great deal of "noise," marks that add little real information. In most cases, however, it is the long-term trends that enable students to make the most meaningful comparisons. By eyeballing a line through the center of each plot, students can determine a rough average for each set of measurements and highlight the long-term trends. See Figure SE-L-2.

Once students draw an "average line," they can superimpose it on other "average lines." For example, students can superimpose an "average line" of the minimum temperatures at their site onto the plot of their site's maximum temperatures to see if both temperatures rise and fall in the same way. Also, students can examine temperature patterns from different years by superimposing the "average lines" of the maximum and minimum temperatures from one year on a similar graph from another year. Students can also see how trends at different sites compare by superimposing the "average lines" from one site onto the plot of the temperatures at another site.

Step 3: Have students analyze the graph of these data by considering questions such as:

- What is the general shape of the average line?
- What does the shape of the average line enable us to say about our site?
- What is the approximate difference between the daily maximum and minimum temperatures throughout the year? How does this difference vary over the year?

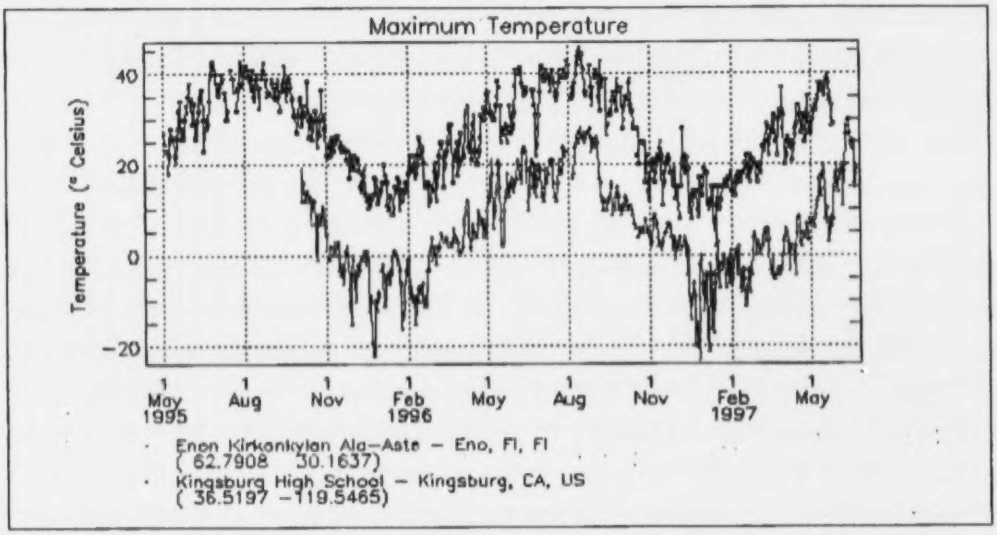
Note: This analysis can be conducted as a class discussion. If the graph is printed for each student, it can also be done in small groups or assigned as homework. Have students copy or paste the graph into their GLOBE Science Notebooks and record their analysis and any questions that arise.

Step 4: Have students find another GLOBE school about 100 km away and repeat Steps 1-3 for this school.

Note: This step asks students to find a school at approximately the same latitude as theirs (100 km north or south is roughly equivalent to 1° of latitude). Climatic changes happen gradually unless there is some dramatic elevation or geographic change over a short distance. As a result, by analyzing the data from a nearby school, students are likely to see similar temperature patterns. When there are differences, their knowledge of the local geography should help them pinpoint reasons for the differences such as one site is coastal and the other is inland, one site is at a higher elevation than the other, or one site is behind a mountain range.

This step builds students' graph-analysis skills by having them compare graphs with only a few significant differences. Also, because they are familiar with the local geography, this step increases the likelihood that students will identify key factors that influence temperature patterns. By pre-

Figure SE-L-3: The maximum temperature plot from GLOBE sites in Finland and California generated by the graphing tool. Note that the California site has reported data over a longer time period.



selecting a nearby site with sufficient data, you can greatly expedite this step. See *Finding a Nearby GLOBE School* and *Finding GLOBE Sites With Many Reported Measurements* in the *Appendix* and *Using the GLOBE Graphing Tool* in the *Toolkit*.

Step 5: Have students describe how the temperature patterns at the nearby site are similar to and different from theirs. For each difference they observe, have students suggest reasons that might explain such variations. After students work together in small groups, conduct a class discussion that summarizes the comparison. Possible points of comparison include:

- How does the timing of the year's maximum and minimum temperatures compare?
- How does the spread between daily maximum and minimum temperatures compare?
- How do the general shapes of the graph lines on the two graphs compare?
- What conclusions about seasons can be drawn based on the temperature patterns at these two sites?
- Do the temperature levels change similarly after the solstices and equinoxes?

Note: To facilitate comparisons, the graphing tool can be used to plot one parameter such as maximum temperature for two sites. See Figure SE-L-3. If graphs are printed for each student, this step could be done in small groups or assigned as homework. Have students sketch or attach print outs of the two graphs and record their analysis and any questions that arise in their GLOBE Science Notebooks.

Step 6: Have students choose another GLOBE site at least 1000 km away that is likely to be climatically different. Have them repeat Steps 1-5

Note: The intention of this step is to find a GLOBE site with an annual temperature pattern quite different from the two already considered. The analysis could be assigned as homework.

Step 7: Have students list factors that might cause the patterns to be different.

Note: Use a wall map of the world or the maps found under GLOBE Visualization

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to focus attention on differences in latitude and elevation, and in proximity to oceans and other significant geographic features. Have students record the factors and any questions that arise in their GLOBE Science Notebooks.

Step 8: Since every site has a combination of factors, conduct a class discussion based on the Venn diagram below. See Figure SE-L-4. In their GLOBE Science Notebooks, have students write a general statement about how latitude, elevation and geography influence their local temperature patterns.

Note: Students should understand that it is important to know a site's latitude, elevation and geography before drawing conclusions about its temperature patterns.

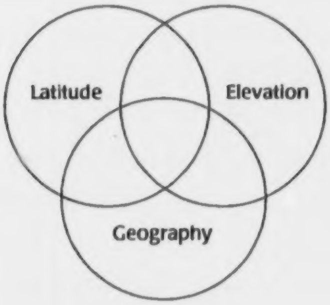


Figure SE-L-4: Every site has a combination of factors that influences the annual patterns of its parameters

Step 9: Ask each group to select one of the factors that might account for temperature pattern differences between the distant site and theirs. Have group members write a plan for investigating this factor, including how to use GLOBE data to test their hypotheses. For example:

Elevation: Compare the annual temperature patterns of sites at different elevations.

Latitude: Compare the annual temperature patterns of sites at different latitudes.

Coastal versus Inland: Compare the annual temperature patterns of sites at different distances from oceans — where do the effects of a marine climate end? They might also compare the marine effect along different coasts.

Note: Different coasts can have different marine effects. For example, the Atlantic and Pacific coasts of the U.S. have different current patterns and prevailing winds that result in different kinds of marine climates. However, both these marine climates moderate temperature extremes and provide considerable moisture to the air.

Additional Factors: Many parts of the world have factors that pertain only to a local region. For example, students could compare sites near to and far from the Gulf Stream, the Santa Anna winds, the Sahara Desert, the Amazon basin, coastal mountain chains, rain shadows, and prairies. Also, they could investigate what kind of influence the size of a continent and the direction of the prevailing winds can have.

Note: To confirm an influence, students will have to keep all other factors constant. For example, to see if elevation has an effect, students must find sites that differ in elevation but have similar coastal-continental locations, latitudes, and proximity to significant geographical features. If the only difference in the sites is elevation, then any differences in temperature patterns can be ascribed to elevation. To bolster confidence in any pattern they find, students will also need to use data from several sites and from a significant time period (e.g., a year). An effect seen by comparing data from only two sites or from a single day is vulnerable to errors and short-term changes and is very unreliable. Have students record their hypotheses and procedure in their GLOBE Science Notebooks.

Step 10: Have students follow their plan and summarize any effects they discover.

Note: Have students record their data, analysis and conclusions in their GLOBE Science Notebooks. They can share their investigation, conclusions and further questions with another school (such as the ones selected for comparison) using GLOBEMail.

Step 11: To further investigate how these factors influence seasonal patterns, have students repeat Steps 1-10 using precipitation and any other parameters they deem important in characterizing a season.

Note: For a mini-investigation in how to determine whether one parameter such as temperature influences another such as precipitation, see "How Can One Tell Whether Two Parameters Are Interrelated?" in the appendix.

Step 12: In their GLOBE Science Notebooks, have students write statements about:

a) how latitude, elevation and geography influence the seasonal patterns of the parameters measured in the GLOBE program; and

b) how the annual patterns of the parameters measured in GLOBE are interrelated.

Assessment

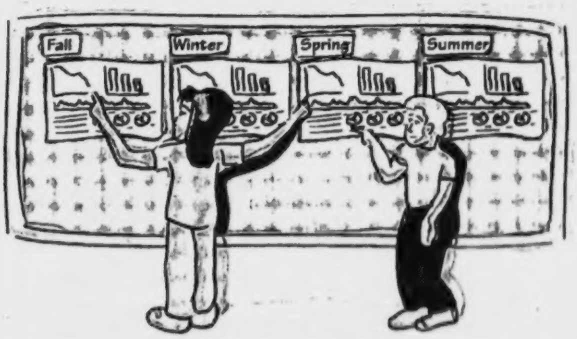
By the end of this activity, students should be able to use graphs and data to support the claim that seasonal patterns are influenced by a combination of latitude, elevation and geography.

All levels:

Poster reports, papers, and multi-media and oral presentations require that students organize and prioritize their thoughts and present their understanding coherently. Consequently, they are effective techniques for assessing students' mastery of concepts, skills and processes. The quality of the information recorded in their notebooks is also an important component in assessing students' ability to communicate their science. Examine their notebook entries, and have them use their GLOBE Science Notebooks to develop their reports and presentations.

Have students demonstrate their understanding of how latitude, elevation and geography influence seasonal patterns by having them respond to questions such as:

- Why are patterns at our site so similar to those at the site 100 km away?
- Why are there such differences between our site and the one 1000 km away?
- What factor(s) did you investigate, how did you do it and what did you conclude?
- Discuss how latitude, elevation and geography influence each parameter measured in GLOBE.
- What are some geographical features that influence seasonal patterns in our area? Describe how they influence the patterns and use data to support your claim.
- How can there be distant sites that experience patterns similar to ours while at the same time there are other distant sites that experience patterns different from ours?



- When considering latitude, elevation and geography, does one seem to be more important than the others in determining local seasonal patterns?
- What would you want to know about a site before commenting on its seasonal patterns? Explain why such information is important.
- Why is temperature alone a poor indicator of a season?

  Note: Temperature is variable over the short term and is influenced by other variables such as latitude, elevation and geography. For example, summer at the poles can still be cold and spring at the base of a mountain is different from spring at its summit. One needs to know a location's latitude, elevation and geography to understand the seasonal patterns.

Advanced:

- How would the graphs of a site change were it moved to a different latitude, elevation or geographical setting?
- Provide students a graph of an annual pattern that is inconsistent with that pattern at their site. Students should be able to identify specific ways the "mystery" pattern is different from theirs.

  Note: You could draw a hypothetical pattern or use one from another site.
- How do seasonal fluctuations relate to the timing of the solstices? Equinoxes? How soon after the solstices do changes begin to occur? Is the lag time the same for each season? For each solstice?

  Note: Temperature levels are influenced by the energy available from the sun. Because the solstices are the dates that correspond with insolation extremes in the temperate and polar zones, the solstices represent points in a temperature's annual cycle in these zones. However, it takes time for the atmospheric temperatures to respond to these insolation extremes, so there is a lag time of several weeks before the new levels of insolation have a significant affect on temperature. In this activity, students will discover lag times as they check whether temperature levels in the temperate and tropical zones change on the date of the solstices. Because sites have different latitudes, elevations and geographical settings, different sites will have different lag times. Note that on the equinoxes, the sun is directly over the equator. Consequently, the equinoxes represent the insolation extremes in the tropical zone.

How Do Seasonal Temperature Patterns Vary Among Different Regions of the World?

Purpose

Students use GLOBE visualizations to display student data on maps and to learn about seasonal changes in regional and global temperature patterns.

Overview

Students use the GLOBE Student Data Archive and visualizations to display current temperatures on a map of the world. They explore the patterns in the temperature map, looking especially for differences between the Northern and Southern Hemispheres, and between equatorial regions and high latitudes. Then students zoom in for a closer look at a region which has a high density of student reporting stations (such as US and Europe). They examine temperature maps for the region, from four dates during the past year (the solstices and equinoxes). Students compare and contrast the patterns in these maps, looking especially for seasonal patterns. At the end of the activity, students discuss the relative merits of different types of data displays: data tables, graphs and maps.

Time

Approximately three class periods

Level

Grades 3-12

Key Concepts

Temperatures vary from one location to another around the world.

Global temperatures patterns vary from one season to the next.

Local latitude, elevation and geography affect seasonal temperature patterns.

Current weather conditions affect regional and global temperature patterns.

Skills

Mapping data with the GLOBE Student Data Server to explore seasonal temperature patterns

Comparing graphs, maps and data tables as tools for data analysis

Materials and Tools

Access to the GLOBE Data Server

A map of the world

Acetate and markers (optional, so students won't mark directly on maps)

Preparation

You may want to display, print and make copies of the maps before class.

Prerequisites

We recommend that students first do *What Are Some Factors That Affect Seasonal Patterns?*, so that they have experience with using graphs to explore seasonal changes in data from individual schools, and so that students have a basic understanding of factors affecting seasonal changes in temperature.

Background

In this activity, your students use GLOBE's visualization tools to explore seasonal patterns in global and regional temperature data. This serves two purposes. First, students learn about seasons in a global context. Second, students learn how to use GLOBE's mapping tool to see global patterns in GLOBE student data.

Special Note: Some regions do not yet have enough reporting stations for thorough analysis.

For the time being, there are regions of the world (such as the United States and Europe) which have large numbers of schools reporting data, whereas other regions have fewer stations. Therefore, when you look at GLOBE visualizations, you will find some areas of the world with ample data for the types of analyses described here, whereas other areas may be too sparse for adequate analysis. Recognizing this temporary constraint, this activity includes both global studies (using the full scope of GLOBE reporting schools) and regional studies (which focus on areas with many reporting sites). Eventually, as GLOBE grows, your students will be able to do more and more global studies.

Mapping Data with the GLOBE Visualization Tool

Please refer to the color maps displayed in Figure SE-L-10 through SE-L-17. GLOBE's visualizations display student data in maps. These visualizations are especially powerful tools, and can be used to help students conduct a variety of investigations. In essence, you select the region that you want displayed, the type of data, and a date and time. Then the GLOBE software creates the requested map, and sends it to you over the Internet.

There are two types of maps that can be displayed: dot maps and contour maps

Figure SE-L-10 is a dot map. This shows each reporting school as a colored dot. The color of the dot corresponds to the value reported by the school. This type of map is best when you want to know where the reporting schools are located, and get a sense of the individual data values (as represented by the color).

Figure SE-L-11 is a contour map. This map uses the raw data to create contours, such as the temperature bands in the example. This type of map is best when you want to explore patterns in the data. You can use the color key to find out what values are indicated by each band. Also, there may be regions of the map without contours. These are areas in which there are no reporting stations.

For these activities, we recommend contour maps because we are more interested in the patterns than in the actual values. Your students will focus primarily on the shape of the temperature bands (noting, for example, where a given band dips down toward the equator).

Your students may quickly learn how to work with contours, since these are the same types of temperature maps that appear in newspapers and on TV, and appear in science textbooks. If your students are confused, you might want to have them work with a data map to make their own contour map. First, use crayons to circle all the points in each temperature range (for example, use red to circle all points with a temperature of 20-29, blue for temperatures 30-35, etc.). Then have your students use crayons to draw bands connecting the points that are the same color.

Temperatures Vary from One Location to Another Around the World

Your students begin by displaying current temperatures, as reported by students around the world. For example Figure SE-L-12 shows a map of student data from all currently reporting schools. In the activity, you will have students explore the map, looking for global patterns. In this example, notice that:

1. There are gaps in the data, because some parts of the world do not yet have GLOBE schools. The world coverage will improve over the years.
2. Since the data are from December, the Northern Hemisphere is generally cooler than the southern hemisphere
3. There are variations in the temperature patterns based on current weather and

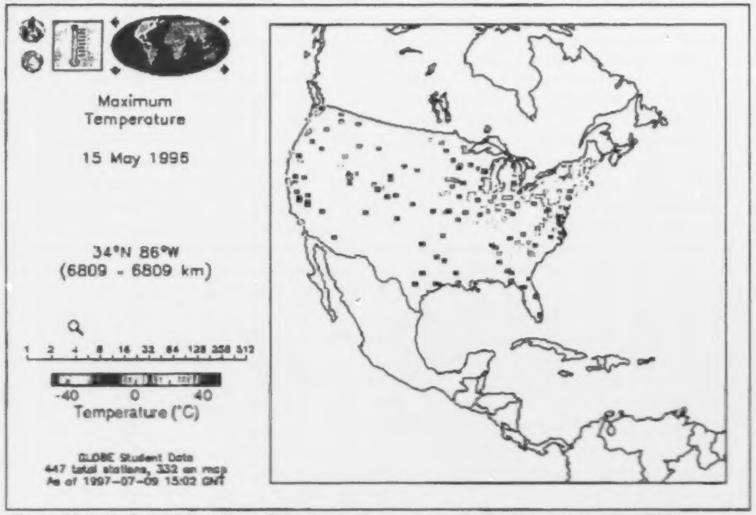

Maximum Temperature
15 May 1996
34°N 86°W
(6809 - 6809 km)
1 2 4 8 16 32 64 128 256 512
-40 0 40
Temperature (°C)
GLOBE Student Data
447 total stations, 332 on map
As of 1997-07-09 15:02 GMT

Figure SE-L-10: GLOBE Dot Map of Maximum Temperatures in the U.S., on May 15, 1997

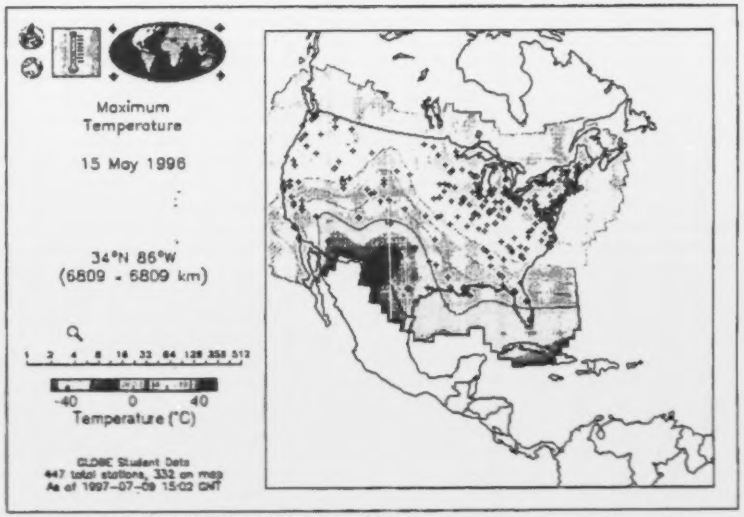

Maximum Temperature
15 May 1996
34°N 86°W
(6809 - 6809 km)
1 2 4 8 16 32 64 128 256 512
-40 0 40
Temperature (°C)
GLOBE Student Data
447 total stations, 332 on map
As of 1997-07-09 15:02 GMT

Figure SE-L-11: Same GLOBE Data as a Contour Map

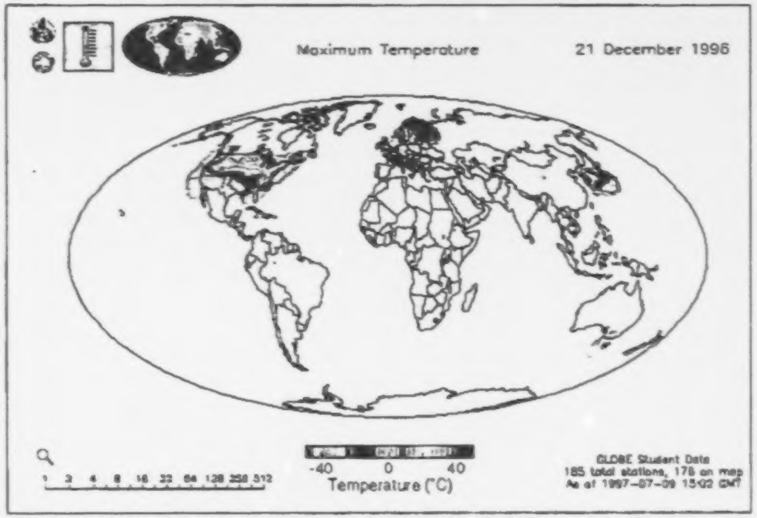

Maximum Temperature
21 December 1996
1 2 4 8 16 32 64 128 256 512
-40 0 40
Temperature (°C)
GLOBE Student Data
185 total stations, 178 on map
As of 1997-07-09 15:02 GMT

Figure SE-L-12: World Temperature Patterns on December 21, 1996 (These maps will become more complete as additional GLOBE Schools begin submitting data.)

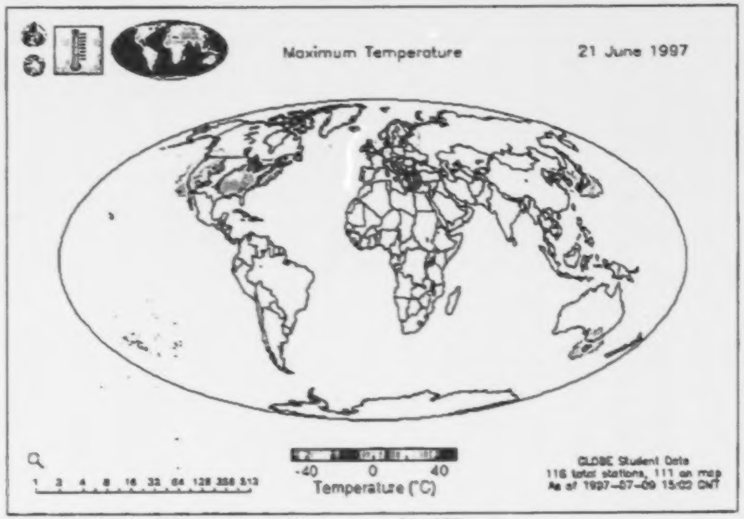

Maximum Temperature
21 June 1997
1 2 4 8 16 32 64 128 256 512
-40 0 40
Temperature (°C)
GLOBE Student Data
116 total stations, 111 on map
As of 1997-07-09 15:02 GMT

Figure SE-L-13: World Temperature Patterns on June 21, 1997

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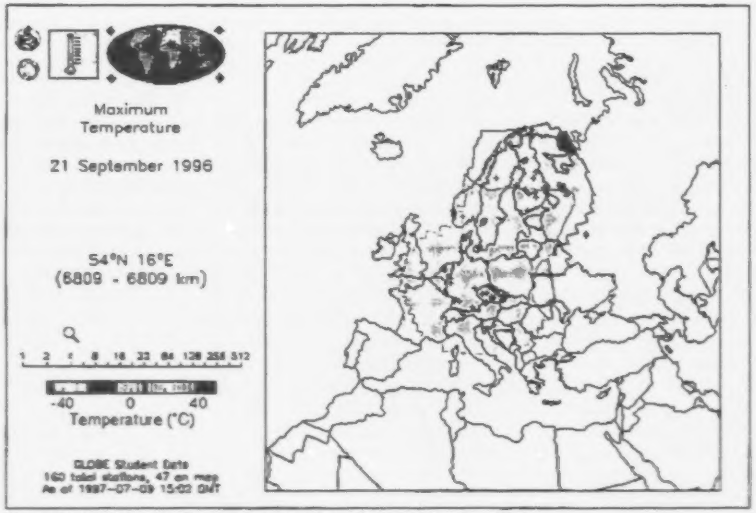
Maximum
Temperature
21 September 1996
54°N 16°E
(6809 - 6809 km)
1 2 4 8 16 32 64 128 256 512
-40 0 40
Temperature (°C)
GLOBE Student Data
160 total stations, 47 on map
As of 1997-07-09 15:02 GMT

Figure SE-L-14: Europe Temperatures in the Fall - September 21, 1996.

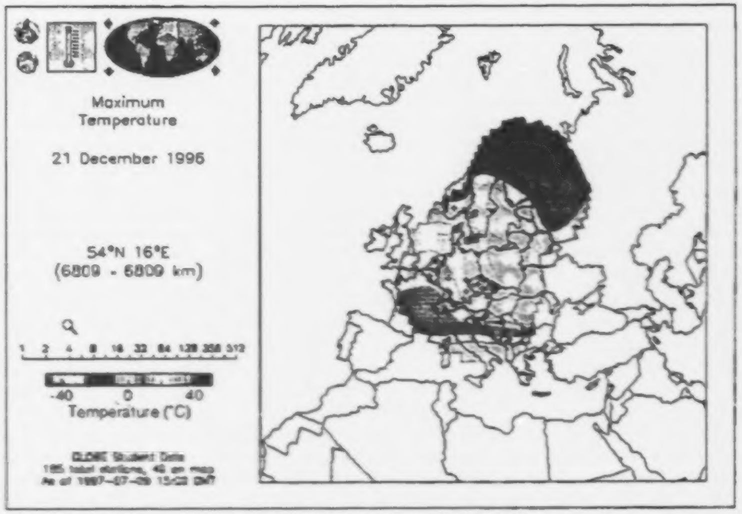
Maximum
Temperature
21 December 1996
54°N 16°E
(6809 - 6809 km)
1 2 4 8 16 32 64 128 256 512
-40 0 40
Temperature (°C)
GLOBE Student Data
185 total stations, 45 on map
As of 1997-07-09 15:02 GMT

Figure SE-L-15: Europe Temperatures in the Winter- December 21, 1996.

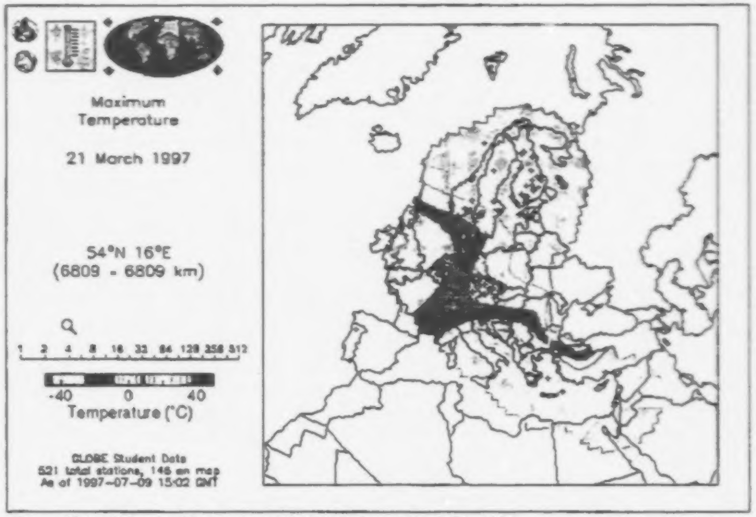
Maximum
Temperature
21 March 1997
54°N 16°E
(6809 - 6809 km)
1 2 4 8 16 32 64 128 256 512
-40 0 40
Temperature (°C)
GLOBE Student Data
521 total stations, 146 on map
As of 1997-07-09 15:02 GMT

Figure SE-L-16: Europe Temperatures in the Spring - March 21, 1996.

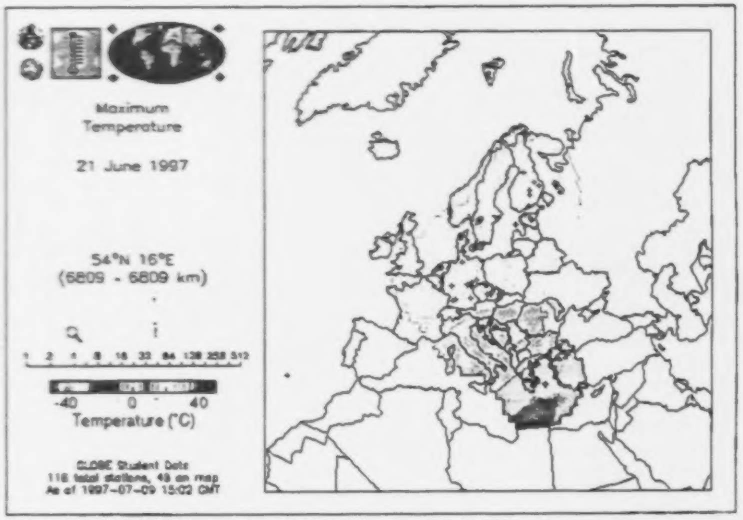
Maximum
Temperature
21 June 1997
54°N 16°E
(6809 - 6809 km)
1 2 4 8 16 32 64 128 256 512
-40 0 40
Temperature (°C)
GLOBE Student Data
116 total stations, 48 on map
As of 1997-07-09 15:02 GMT

Figure SE-L-17: Europė Temperatures in the Summer - June 21, 1996.

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local climatology (e.g. France is warmer than Northeastern U.S., even though they are both at the same latitude)

Temperature Patterns Vary from One Season to the Next

When your students display temperature maps from four different days throughout the year, they are able to explore the seasonal variations in global temperatures, as shown in the above sample maps. (For more detailed analysis, your students could display data from each month of the year).

In these sample maps, Figures SE-L-14 through SE-L-17, notice that:

1. It is generally warmer in the summer and colder in the winter.
2. Fall and spring are similar in temperature.
3. Regardless of season, it is warmer the farther south you look.

Regional Maps Show Greater Detail in the Temperature Patterns

When you zoom in for a closer look at a region of the world, you can see more detail. This enables you to see regional patterns more clearly. In Figure SE-L-14 through SE-L-17, you can see the differences among four different views, each representing a different season. For example:

1. Temperatures are generally warmer in the summer than the winter.
2. Weather patterns are not constant throughout the year (for example, the curves in the temperature contour on June 21 is not the same as on Sept. 21).

Your students can extend the investigation by looking at seasonal variations in other types of data, such as precipitation type and amount, soil moisture or water temperature. Your students can also explore how the local variations are affected by local geography and elevation.

What To Do and How To Do It

Note: These activities work best if students gather around the computer or take turns, so that they can work directly with the GLOBE visualizations. Or you can print the GLOBE maps and make copies for each student or for groups of students.

Step 1: Display a map of recent temperatures world-wide.

Use the GLOBE data system to access recent temperature data (either minimums or maximums) from all student sites around the world, and display the data on two types of maps: data map and contour map. You might want to choose yesterday's data, since some schools may not yet have reported today's data..

Step 2: Students explore the global temperature maps.

Begin with the dot map. Have your students examine the map. First look for your own site. This shows the temperature data reported by your school. It is shown as a colored dot, with the color corresponding to the temperature. Next, look for other sites, and compare their location and temperature with your own. Find other schools with the same temperature (color) as your own. Find other schools in your own country. Find a school in each continent. Then find the absolute warmest location, and the absolute coldest location.

As noted in the background section, you will see that some areas have many GLOBE schools reporting data, and other areas have few or none. As more schools begin reporting data, your students will be better able to see global patterns. You can use this opportunity to help your students see the importance of having many schools world-wide and having each report their data every day.

Next, have your students look for global patterns in the temperature data. Your students might notice that:

1. Temperatures are warmer in equatorial regions, and colder as one moves further north or south.
2. The Northern Hemisphere is warmer than the Southern Hemisphere or vice-versa.

Step 3: Students zoom in for a local view, and explore regional seasonal variations.

Ask your students what they think the global temperature map will look like at different times of the year. This can be a useful discussion, helping students to think about global seasonal patterns, and to make their own predictions. It also helps you as teacher to find out what your students know and what misperceptions they might have.

Tell your students that they will now zoom in for a closer view of one or more regions of the world. Have them select areas of the world where there are many data points, and then request a contour map for that region. Make sure your students understand what the contour map shows (same data as in the data map, but presented as temperature bands). Ask them what shapes and patterns they see in the contour map.

Now select maps of the same region, from four different dates during the year. This will enable them to examine how the temperature patterns change over the year. Ask your students what four days would give a good cross-section of the year. Discuss your students' suggestions. Either proceed with whatever dates they suggest, or guide the discussion to selecting the four seasonal transition points (June 21, Sept. 21, Dec 21, Mar 21). You might want to discuss the significance of these dates (solstices and equinoxes). Another approach is to select 12 dates, one per month. This will give your students more detail in the year-long variations.

Access, display (and if possible print and make copies of) the temperature map for each of the four days.

Now have your students study the maps. What similarities do they see from one season to the next? What differences? You want to promote student inquiry and investigation here, so don't simply tell them what the patterns are, but let your students explore the maps and discuss individually or in small groups.

Discuss what they found. They are likely to see:

1. One season tends to be warmer than another.
2. Regardless of season, it tends to be warmer as one moves closer to the equator.
3. Weather patterns are not constant throughout the year. The shape of the temperature bands will vary from one day to the next.
4. If you look at schools in the same latitude, you will find differences in their temperatures.

Ask your students why these patterns occur. For example, they may understand that the northern and southern hemispheres have opposite seasons. Or they may comment that local weather conditions impact on the seasonal variations (coastal regions tend to have more stable temperatures throughout the year.)

Step 4: Students compare and contrast data tables, maps and graphs. See Figure SE-L-18 through SE-L-20.

In this activity your students use GLOBE maps. In other activities, students use graphs and in others they use data tables. These three types of data displays enable your students to visualize, understand and interpret the data. At this point, it is worth exploring with your students the merits and applications of these three types of data displays.

Show your students these three types of data displays. Ask your students what type of information they see in each display. Then discuss with your students the advantages and disadvantages of each type of display.

For example, your students might notice that:

Maps show how data varies from one location to another. You can see world-wide or regional patterns such as the warmer temperatures in the equatorial regions of the world.

Graphs show how data changes over time. You can see annual patterns such as the warmer temperatures in summer and the colder temperatures in winter.

Data tables show lots of data values in a grid. You can quickly find any type of data for any location, such as the temperature and precipitation amount for a given city.

Post a copy of the map, graph and data table on

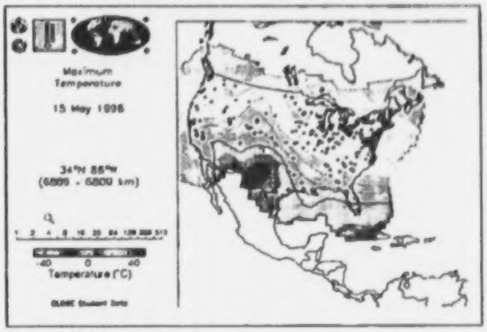


Figure SE-L-18: Maps

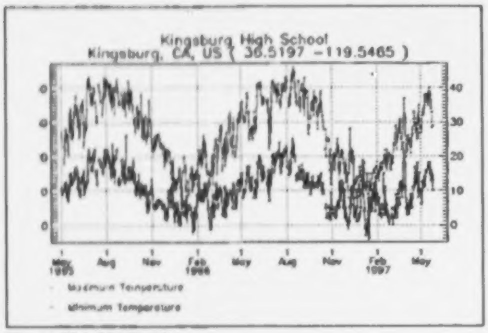


Figure SE-L-19: Graphs

Data for 19970707 to 19970707

Atmospheric Temperature						TEMPERATURE		
MG	YY/MM/DD	HR	LAT	LONG	ELE	CURR	MAX	MIN
AT	97/07/07	20	47.6589	-117.4250	675	24.0	34.0	12.0
AT	97/07/07	19	32.2217	-110.9258	836	36.1	41.7	25.6
AT	97/07/07	19	36.5197	-119.5463	27	34.0	39.0	17.0
AT	97/07/07	19	33.7769	-118.0386	7	24.0	24.5	17.0
AT	97/07/07	19	45.4556	-112.1961	1594	29.0	29.0	7.0
AT	97/07/07	18	33.7769	-118.0386	7	23.0	26.0	16.0
AT	97/07/07	18	40.7608	-111.8903	1711	29.0	34.0	16.0
AT	97/07/07	18	47.6064	-122.3308	67	21.0	-99.0	-99.0
AT	97/07/07	17	57.7883	-152.4030	35	12.0	15.0	11.0
AT	97/07/07	17	35.8422	-90.7042	69	31.0	31.5	17.5
AT	97/07/07	17	39.7683	-86.1581	259	28.0	-99.0	-99.0
AT	97/07/07	17	39.2403	-76.8397	57	30.0	-99.0	-99.0
AT	97/07/07	17	44.8817	-69.4458	88	28.0	30.0	7.5
AT	97/07/07	17	39.7558	-77.5782	375	27.0	27.0	16.0

Figure SE-L-20: Data Table

a bulletin board, and have your students write under each type of display some interesting observations that they see in that display. For example, under the graph they might write the coldest day of the year. Under the map, they might write the coldest location in the world. Then have them write some questions that could be answered with that type of display.

You may need to revisit this comparison of different types of data displays, as students plan their own investigations, such as in step 5 below. Students need to be sure that they're using the most appropriate display for their data analysis.

Step 5: Students use an inquiry-based approach to extend the investigations.

There are several ways that you and your students can extend the investigations. For example:

- Print out maps from two consecutive days (such as June 21 and June 22). Using these two maps, students can explore short term variations versus long-term seasonal changes. For example, they might see minor changes in the shapes of the temperature bands from one day to the next, and larger changes in the overall temperatures from one season to the next.
- Pick two locations for more detailed comparison. For example, your students might find that a town on the Mediterranean coast has less variation between winter and summer than a place in central Canada. This might be because the water of the Mediterranean has a moderating effect on temperature variations. If so, do other coastal locations have similarly moderated temperature variations?
- Display other data on the maps, such as precipitation amount. Students might compare patterns of snowfall in the winter versus the summer and compare northern hemisphere vs. southern hemisphere.

In each of these extensions, be sure your students use an inquiry-based approach, in which students:

1. Begin by exploring the displays to see what patterns and questions emerge.
2. Select a question that seems especially interesting.
3. Decide what resources can help students investigate the question. Especially focus on use of GLOBE data (each of the examples above uses GLOBE data).
4. Conduct the investigation, either individually or in teams.
5. Share the findings with other students.
6. Think about what new questions emerged that could lead to further investigations.

For these investigations to succeed, they need to be genuinely engaging for the students — in other words the student(s) should really care about the answer. One goal of the activities in this seasons module is to stimulate such interests. In that sense, these activities not only have their own intrinsic value, but also serve as launching pads for further investigations.

Assessment

In this activity, your students have learned about seasonal patterns in global temperature data. They also have learned about GLOBE's map visualization tools. To assess student learning, use the following two steps:

1. Ask your students to use the GLOBE data server to create a contour map of student temperature data from July 15 and January 15 (these dates are near the peaks of summer and winter, and are different from the maps they've already used). Check to make sure each student is able do this activity correctly. You might have a student who knows how to do this help you by observing the other students as they go through the steps, to see who knows how to do this, and who has what kinds of problems.
2. If possible print out the July 15 and January 15 maps from the previous step, and make copies for your students. If you can't do this, then use the sample Dec 21 and June 21 temperature maps that appear in the background section. Then have your students indicate which is summer and which is winter. If you wanted to extend the assessment further, you might print out a 6 month sequence from July 15 to January 15 (one map from each month), cut out or cover over the date on each display, and then ask your students to sort them into the proper sequence. Then ask them to write down what evidence they used to put them in this sequence.

What Can We Learn by Sharing Local Seasonal Markers with Other Schools Around the World?

Purpose

This activity promotes collaborations among teachers during and after the GLOBE teacher training program. It helps teachers and students learn how to work with the GLOBE data system and GLOBEMail email. It also helps teachers and students learn how the protocols are interconnected and can support inquiry-based investigations.

Overview

The central topic of this activity is seasonal markers, which are the various biological, physical and cultural changes which mark transition points in the annual cycles of seasons. Examples are the first snowfall, the beginning of monsoon rains, and the summer solstice. Teachers begin this activity in the GLOBE teacher training workshop by discussing the differences in seasonal patterns among their respective communities. Then the teachers agree on a list of 5 seasonal markers which they would like the teachers and their students to observe in their own communities. When teachers return to their schools, they engage their students in the activity, and use GLOBEMail over the next several months to share the seasonal marker observations. By comparing GLOBE data with the shared seasonal marker information, students are able to conduct their own collaborative investigations of seasonal patterns. The collaboration also promotes on-going collegial support among the teachers to help each other in implementing the full GLOBE Program.

Time

One hour and a half in the GLOBE Teacher Training Workshop.

About 15 minutes per week over the next several weeks.

Level

Teachers and students at all levels

Key Concepts

Seasonal patterns, with a special focus on seasonal markers

Skills

Communicating data and comments using GLOBEMail

Exploring seasonal patterns in the GLOBE Student Data Archive

Collaborating with other GLOBE schools

Materials and Tools

Access to GLOBEMail

World maps (black and white line master on 8 1/2 x 11 sheet) - one per participant

Preparation

Teachers begin this activity at the workshop, then continue it with their students

Prerequisites

Teachers need to attend the GLOBE Teacher Training Workshop, during which this activity is launched.

Background

Seasonal markers are indicators of seasonal change. For example, the first appearance of a particular migrating bird, such as a robin, is a classic marker of spring. Examples of other markers are ice melting on lakes, the thawing of soil, emerging leaves on trees, and warming temperatures. Notice that in this list there are examples relating to hydrology, soil, biology and atmosphere. In this activity, you learn more about seasonal markers and begin to share observations of markers with your teacher colleagues..

You will use GLOBEMail to communicate with other schools. GLOBEMail is an electronic mail system, in which you can write letters and send them by email to other teachers and students. GLOBEMail is different from the GLOBE data system in which you send the data values from the GLOBE protocols. Rather, GLOBEMail enables you to go beyond the raw data, and have more open-ended communications, to share ideas, to reflect on your experiences teaching GLOBE, and to help other teachers as you work through some of the challenges of implementing GLOBE. Such collegial support can be a real help to you as you begin to implement GLOBE. For your students, GLOBEMail enables them to work collaboratively on investigations with other students throughout the world.

Seasonal markers are not a standard GLOBE protocol and are not part of the GLOBE data system. Therefore, you and your students will use GLOBEMail as an informal way to share the seasonal marker observations. As shown in the example below, you simply enter the marker observation as a comment in the GLOBEMail message. Be sure to describe the marker and include the data. It also helps to add a personal note that might make the observation more interesting or informative.

These GLOBEMail messages also provide the opportunity for you to share other comments about your experiences teaching GLOBE. You know the teachers who will receive this message, since they were your colleagues in the GLOBE Teacher Training Workshop. Therefore, they are likely to be interested and perhaps helpful in their response to your GLOBEMail messages. Your students can also use GLOBEMail to share ideas for and results of collaborative investigations.

GLOBEMail

To: Seasonal Markers Team

From: *School name*

Today (Nov 13) was the first snowfall. It was only a dusting, but this is the earliest we've ever had snow.

Incidentally, we have just begun to use the data server to explore plotting data on graphs. We were surprised by some abnormal "blips" in the local temperature graph. When we investigated this, we found out that a student had entered Fahrenheit temperature instead of Celsius. So, we suggest graphing your data as a way to find errors in your data.

What To Do and How To Do It

Phase 1 – During the GLOBE Teacher Training Workshop

Step 1: Workshop leader explains the purpose

The workshop leader introduces this activity, explaining that this activity has three goals. First, it helps teachers understand the GLOBE seasons module. Second, it helps teachers stay in contact and help each other after the GLOBE Teacher Training Workshop. Third it provides an interesting seasons investigation for your students.

Through this activity, students and teachers share detailed observations of seasonal changes in their local communities, and work together to investigate regional patterns in the seasonal changes. Teachers in previous workshops have requested a way to maintain contact with their new GLOBE colleagues, to help each other implement GLOBE, and to participate in a collaborative investigation using GLOBE data.

Step 2: Groups of teachers discuss seasonal variations

Form groups of about 10 teachers. Distribute world maps, one per teacher. (If all teachers are from a single country or region of the world, it might make more sense to use a regional map.) On the maps, each group plots where each teacher is from. Write the name of the teacher and the town on the map.

Then discuss the differences in seasons among the different locations. For example, some schools might have snow for several months in the year, others might have none. Try to discuss both qualitative and quantitative differences, including when the seasonal changes generally occur. This discussion is richer if there are teachers from many parts of the world. If you don't have such broad geographical diversity, you might spend some time in the discussion speculating on seasonal variations in other parts of the world.

Step 3: Groups of teachers discuss seasonal markers

Next each group discusses seasonal markers. The workshop leader should make sure everyone understands what seasonal markers are (refer to background). Each group brainstorms a list of seasonal markers that might be observed at different times by the different teachers in the group. For each marker, indicate which season it is associated with. (Equatorial regions should use local definitions of seasons such as dry and monsoon.)

Here are some markers that the teachers might identify:

bird migrations
lake freezes
monsoon rains
bud break
mosquitoes
bull frogs croaking
first frost
heavy pollen
first snow
first crocuses
startwhale migrations
leaves begin fall colors
butterfly migration
first tomatoes
first day w/no coat

Step 4: Select which markers to investigate

Bring all the groups together and have each group describe their markers out loud. Then have the full group select five markers which a) all or most of the teachers will be able to observe, b) occur over the next four months, and c) are likely to show variation from one school to another. (The number of markers and the length of time are reasonable figures, but the group may decide on other values.) Make sure each teacher has a list of the selected markers.

Step 5: Workshop leader explains what happens after the workshop

The workshop leader explains that all teachers (with the help of their students) will watch for the occurrences of the seasonal markers, over the next several months. As detailed below, students and teachers will:

- share their observations of the seasonal marker events with the other teachers
- investigate the data from these observations and share their own analyses of the patterns in the seasonal markers
- help each other by sharing their experiences implementing GLOBE
- work together on collaborative investigations with students from other GLOBE schools

Make sure the teachers understand the purpose and nature of this follow-up activity. You should also check on the degree of expected participation. Some teachers may be quite interested in this investigation, and others may not. Among the interested teachers, divide the full group into smaller groups of about ten teachers (more teachers could be overwhelming in terms of the total email). The teachers should also decide if they want to begin right away, or whether they want to wait a few weeks before beginning.

Phase 2 – After the workshop

Step 6: Get started using GLOBEMail

After you finish the GLOBE training session, you should begin to implement the standard GLOBE protocols and learning activities. You can begin to use GLOBEMail at any point.

Send a hello message to your colleagues. You should also begin to receive messages from your colleagues.

GLOBEMail

To: Seasonal Markers Team

From: School name

It is June 12, and the monsoon rains have just begun. This is when we typically have a big party, dancing in the rain. Did you know that the word monsoon is derived from "mausim" which is the Arabic word for season?

Step 7: Send a GLOBEMail message whenever a seasonal marker occurs

With your students, pay attention to the environment around you, noticing when each of the seasonal markers occurs. Whenever it does, send a GLOBEMail message to your seasonal markers teammates, indicating the marker, the date and any other comments you and your students would like to add.

Step 8: Monitor your incoming GLOBEMail for messages, and plot the data

Whenever you receive a GLOBEMail message from one of the participating schools, have your students record the information on a map. You might want to have a different map for each of the seasonal markers. You might also want your students to make a chart listing each marker and the location and date of each observation.

Step 10: Conduct your own investigations!

As you and your students do your own local observations, and as you peruse the observations from the other schools, you and your students may notice some patterns. For example, they may notice that the further south a school is, the sooner they see the first spring robin. Or they may notice that lakes freeze sooner inland than near the coast. Have your students use GLOBEMail to share these speculations with the other schools.

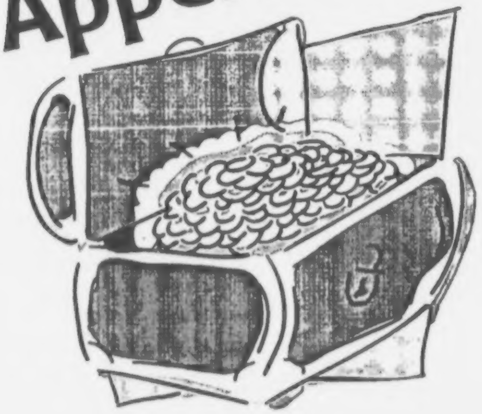
Your students should also use GLOBE's data server to explore GLOBE student data which might provide further insights into the seasonal patterns. They might find that the coldest day of the year is generally one month after the Winter solstice. Or they might find that robins only start to appear after the local temperature has reached an average of 40 deg F. Use GLOBEMail to share these speculations with the other schools.

Your students can extend these investigations with seasonal data. They might find patterns linking

GLOBE data with seasonal markers. They might predict when a particular marker will occur and see how close their guess is to reality. They also can relate the seasonal markers with the other seasons activities described elsewhere in this module.

GLOBE is a wonderful resource for conducting a wide range of investigations. The seasonal markers investigation provides you and your students the opportunity to participate in your own investigations, to share observations and ideas with other schools, and conduct collaborative investigations with other schools around the world. Also, GLOBEMail enables you, as a teacher, to provide mutual support with other teachers as you implement GLOBE. Most importantly, this activity enables you and your students to experience and participate in the excitement of science research enabled by GLOBE's world-wide network of students, teachers and scientists.

Appendix



Pedagogy of the Seasons Investigation

Locating Information on the GLOBE Student Data Server

Mini-Investigation: How Can One Tell Whether Two Parameters Are Interrelated?

Pedagogy of the Seasons Investigation

In the Seasons Investigation, each activity starts with a sequence of highly structured steps. However, as each activity progresses, students get increasing amounts of freedom to conduct their own investigations. This approach prepares students to conduct their own research by developing the necessary skills, deepening their understanding of key concepts, and helping them generate interesting questions worthy of further study.

How This Activity Helps Develop the Idea that Science is a Process of Refining Understanding

General Steps in Refining Understanding

1. Ask Questions and Develop Hypotheses
2. Plan Investigation
3. Collect and Analyze Data
4. Draw Conclusions
   If data are insufficient to support conclusion, return to 3
   If data are sufficient to support a conclusion, go to 5
5. Communicate conclusions
6. Ask follow-up Questions and Develop New Hypotheses

Locating Information on the GLOBE Student Data Server

To Find Any GLOBE Site

1. Click on the "Student Data Server" on the GLOBE Home Page
2. Use the menus to locate the site(s).

If there are only a few sites at your latitude, another approach to finding sites is to have students identify major cities around the world at their latitude. Daily high and low temperatures for such cities are printed in the weather section of most newspapers. However, many major cities are coastal, so make sure students obtain some kind of diversity.

Finding a Nearby GLOBE School

1. Click on the "people" icon (fifth button) on the button bar at the bottom of the GLOBE home page.
2. Scroll to the bottom of the "GLOBE School Interaction" page and click on the "List" button.
3. The next menus will enable you to select the appropriate country and state.
4. When you are at the "Individual School" level, scroll through the list to find a nearby school that has a data icon (a picture of a graph in the third column).
5. Click on the data icon and see how many data points exist for the parameter in which you are interested. If it does not have enough data points or if the data points are for the wrong time period, continue to scroll through the list until you find a data set that meets your needs. If no school in your state meets your needs, consider using data sets from schools at similar latitudes in similar geographical settings. While this will introduce an uncontrolled variable into your data, it will also stimulate an interesting discussion about weather and climate around the world. In addition, it will underscore the importance of submitting to GLOBE a data set to represent your region.

To Find the GLOBE Sites That Have Reported on a Specific Day

1. Click on the Student Data Archive on the GLOBE Home Page.
2. Use the "Get data for most recent day or for some other time period" menu to locate the site.

Another Way To Find the GLOBE Sites that Have Reported on a Specific Day

1. Open the GLOBE Visualizations location on the GLOBE Student Server.
2. Click on "What's New."
3. Click on "try out new system."
4. Select "GLOBE Maps."
5. Scroll down and under "Other Options," click on "Show Table."
6. The list is at the bottom of the page. Click on the column headings to sort the table by that category.

Finding GLOBE Sites With Many Reported Measurements

1. Select "GLOBE Stars" on the Student Data Server home page.
2. Select "Schools providing many observations."
3. Click on the arrow to find the name of the schools in each category.
4. Click on one of the icons to access a school's data or to find out more about the school.
5. So a data-rich site can be readily identified when data from a specific location is required, print out the schools in each category and keep them on file.

Obtaining Average Monthly Data

1. From the GLOBE Home Page, click on the "Student Data Archive."
2. Enter the first few letters of the school you want.
3. Click: "Search."
4. After the search is completed, click on the data icon of the desired school.
5. After clicking the checkboxes of the "Monthly Summary" and desired measurements, click "Retrieve."
6. Once the monthly summary data are obtained, they can graphed by hand or be loaded into a spreadsheet program.

Obtaining Historical Data through GLOBE

In this activity, students will see importance of having reliable data over long periods of time and will appreciate the insights that can be gleaned from using the historical climatic data on the GLOBE Student Server. To access these data:

1. Click on the "GLOBE Resource Room" selection on the GLOBE Home Page.
2. Click on "Weather Information."
3. Choose a site with historic weather data such as Intellicast or the Purdue Weather Processor. Scroll down to the bottom of the Weather Information page to see capsule descriptions of each weather site.

Another historic temperature and precipitation data set provided through GLOBE is from the National Climatic Data Center. It includes historic temperature data from over 6,000 stations around the world dating back hundreds of years, in some cases. The data are available in several presentations: as an average year, as a yearly time series, and as monthly averages. One can also obtain the average and standard deviation of temperatures shown as a function of latitude. These data provide an original data source for discussions of temperatures and seasonal variations around the world.

Mini-Investigation

How Can One Tell Whether Two Parameters Are Interrelated?

Overview

Students create climatographs for their site and the two sites examined in the *What Are Some Factors That Affect Seasonal Patterns? Learning Activity*. They analyze each climatograph to determine if temperature and precipitation patterns are interrelated. Students then examine how the three sites are alike and different based on their temperature and precipitation patterns. Finally, students generate ideas about what might cause the patterns to be different. They repeat this process with other parameters.

Procedure

Step 1: Have student groups obtain the monthly summaries of the *Atmospheric Temperature*, *Precipitation Rain*, and, if appropriate, *Precipitation Solid* data from your site and the two sites examined in *What Are Some Factors That Affect Seasonal Patterns? Learning Activity*.

Note: You can either provide students print outs or have them use the Student Data Archive to obtain these data. If your site has limited amounts of data, use the menus in the Student Data Archive home page to find a nearby GLOBE site whose data you can use. To generate a table of monthly summaries, see *Obtaining Average Monthly Data* in the *Appendix*.

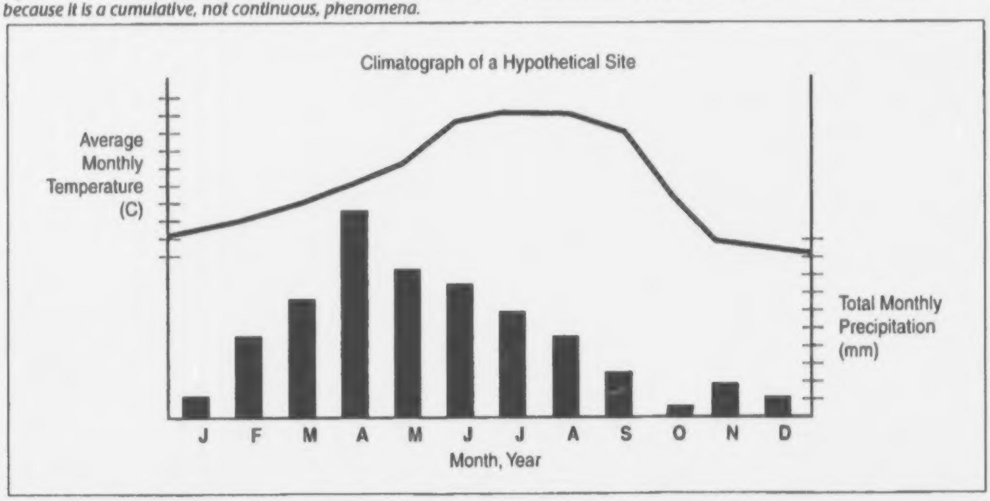
Step 2: If any of these sites have *Precipitation Solid* data (i.e., snow and ice), have students calculate the total amount of precipitation for each month by adding *Water Equivalent* column (under *Precipitation Solid*) to the *Precipitation Rain* column.

Step 3: For each site, have students plot the *Average Current Temperature* and the total precipitation (i.e., *Precipitation Rain* plus *Precipitation Solid—Water Equivalent*) month-by-month onto a single graph for a year. See Figure SE-A-1.

Note: All three average monthly temperatures – the current, maximum and minimum – will show annual trends equally well, and you can have students plot any one of them. Make sure each student puts a copy (hand-written or a print out) of each graph in his or her GLOBE Science Notebook.

Step 4: Have students analyze each graph. See how well they can analyze them on their

Figure SE-A-1: A Climatograph displays a site's temperature and precipitation levels. Precipitation is shown with a bar graph because it is a cumulative, not continuous, phenomena.



own. If they need prompting, ask questions such as:

- When does the wettest month occur? The driest? The hottest? The coldest?
- How is the precipitation distributed over the year?
- What are the maximum temperature and precipitation values? The minimum?
- What temperature range is associated with the maximum precipitation levels? The minimum?

Note: Have students do their analysis of the three sites in small groups and then develop a class-wide understanding of each site by having them share their analyses in a class discussion. The analysis can also be assigned as homework.

Step 5: For each site, have students write a summary statement in their GLOBE Science Notebooks about whether the precipitation and temperature patterns at each site are interrelated. Also, have them write three to five questions relating to temperature and precipitation patterns.

Note: Patterns are said to be interrelated when a change in one causes a change in the other. However, the patterns need not be identical. For example, when temperatures in many regions are at their highest, the precipitation levels are at their lowest. Even though these patterns are opposite, they are still interrelated because when the hot season ends and temperature levels fall, the precipitation levels usually increase. This cause-and-effect relationship is what characterizes interrelated phenomena.

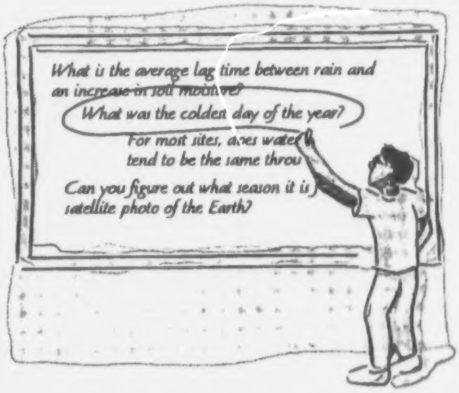
Step 6: Have students compare the three climatographs by creating lists of how the three sites are alike and different. See how well they can analyze them on their own. If they need prompting, ask questions such as:

- In general, which site is the hottest? The coldest? The wettest? The driest?
- In what way are the patterns on the three climatographs most alike? Most different?
- Describe each season based on the temperature and precipitation patterns at these sites.
- Describe the plant and animal life one might find at the distant site.
- Describe how the temperature and precipitation patterns might affect how people live at the distant site.
- What kinds of climates are represented by each of the climatographs? (Ask only if students are sufficiently prepared to answer this question.)

Note: Have students do their initial analysis in small groups and then develop a class-wide understanding of each site by having them share their analyses in a class discussion. The analysis can also be assigned as homework.

Step 7: Have students write a hypothesis in their GLOBE Science Notebooks about what they think causes annual temperature and precipitation patterns at the three sites to be different. Also, have them write three to five questions relating to temperature and precipitation patterns at different sites around the world.

Note: *What Are Some Factors That Affect Seasonal Patterns? Learning Activity* explores how latitude, elevation and geography influence annual patterns. Differences in any of these factors will cause differences in the annual temperature pattern. Since precipitation is


What is the average lag time between rain and an increase in soil moisture?
What was the coldest day of the year?
For most sites, does wate
tend to be the same throu
Can you figure out what season it is
satellite photo of the Earth?

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based on a relationship between temperature and the amount of water vapor in the air, any thing that influences either of these factors will influence precipitation levels. See *Two Key Factors That Influence Precipitation Levels* in the background section for a more complete discussion.

Step 8: Have students share some of their hypotheses and questions relating to temperature and precipitation patterns and create a master list. If questions such as the following do not emerge, add them to the list.

- Are temperature and precipitation levels interrelated?
- Do temperature and precipitation levels follow similar patterns around the world?
- Why are precipitation patterns at the distant site different from those at our site?
- Are precipitation levels influenced by latitude, elevation and geography the way temperature levels are?

Note: Use a wall map of the world or the maps found under GLOBE Visualization to focus attention on differences in latitude and elevation, and in proximity to oceans and other significant geographic features.

Step 9: Following a procedure similar to the one outlined in Steps 3-8, have students choose other GLOBE parameters and investigate how their annual patterns are related to the temperature and precipitation levels.

Step 10: In their GLOBE Science Notebooks, have students write a statement about how the parameters measured in GLOBE are interrelated.

Extension

- Consider having students investigate some of the hypotheses developed in Steps 8 and 9.
- By creating climatographs for sites around the world, challenge students to identify as many different kinds of climates as possible. See the ten climatographs in Figure SE-A-2.

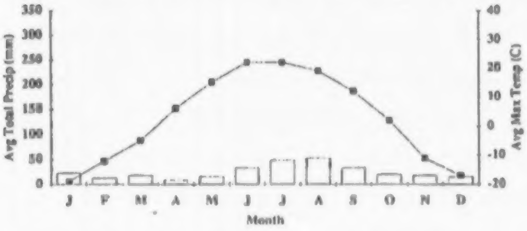
Assessment

By the end of this activity, students should be able to use graphs and data to:

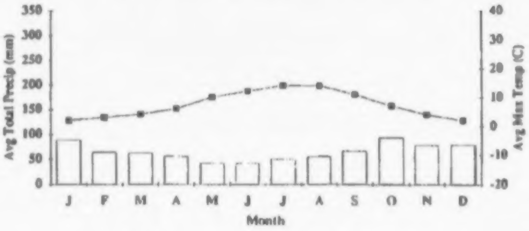
- create a climatograph;
- analyze a climatograph to understand a site's temperature and precipitation patterns;
- make reasonable inferences about a site's plant and animal life based on its climatograph;
- support the claim that seasonal patterns are influenced by a combination of latitude, elevation and geography;
- show that the annual patterns of the parameters measured in GLOBE are interrelated.

Figure SE-A-2: Sample Climatographs: Patterns Associated with Different Climates

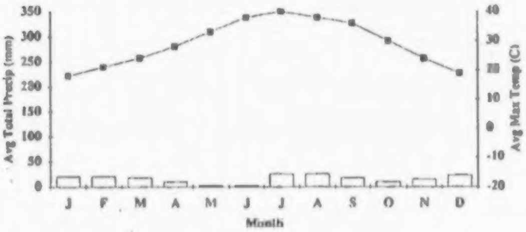
Fairbanks, Alaska, USA (65N 148W 134 m) Polar Continental Dry



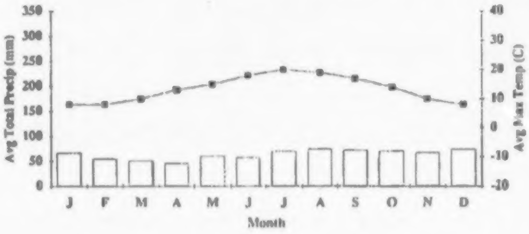
Reykjavik, Iceland (64N 22W 18 m) Polar Marine Tundra



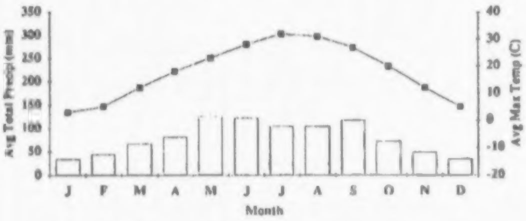
Phoenix, Arizona USA (33N 112W 330 m) Temperate Continental Desert



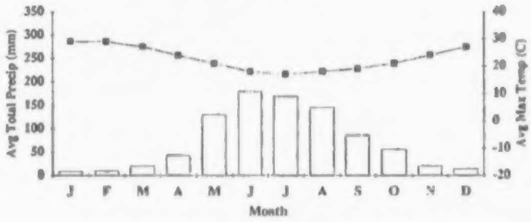
Dublin, Ireland (53N 6W 47 m) Temperate Marine



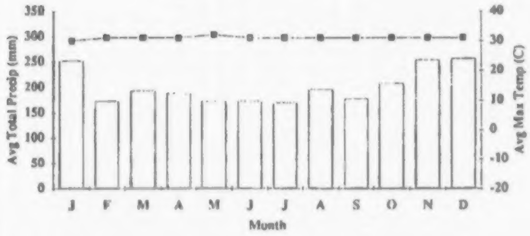
Kansas City, Missouri USA (39N 95 W 226 m) Subtropical Continental Humid



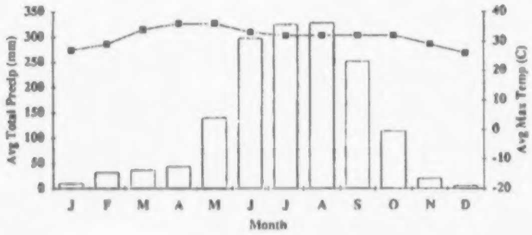
Perth Australia (35S 139E 43 m) Subtropical Dry Summer (Mediterranean)



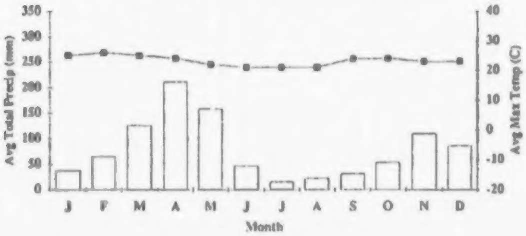
Singapore (1N 104E 10 m) Tropical Wet



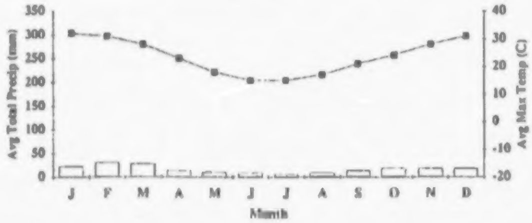
Calcutta, India (23N 88E 6 m) Tropical Wet-Dry (Monsoon)



Nairobi, Kenya (1S 36E 1820 m) Tropical Semiarid Upland



Mendoza, Argentina (33S 69S 801 m) Subtropical Continental Dry (Rainshadow)



☐ *Average Total Precipitation* ----■---- *Average Maximum Temperature*

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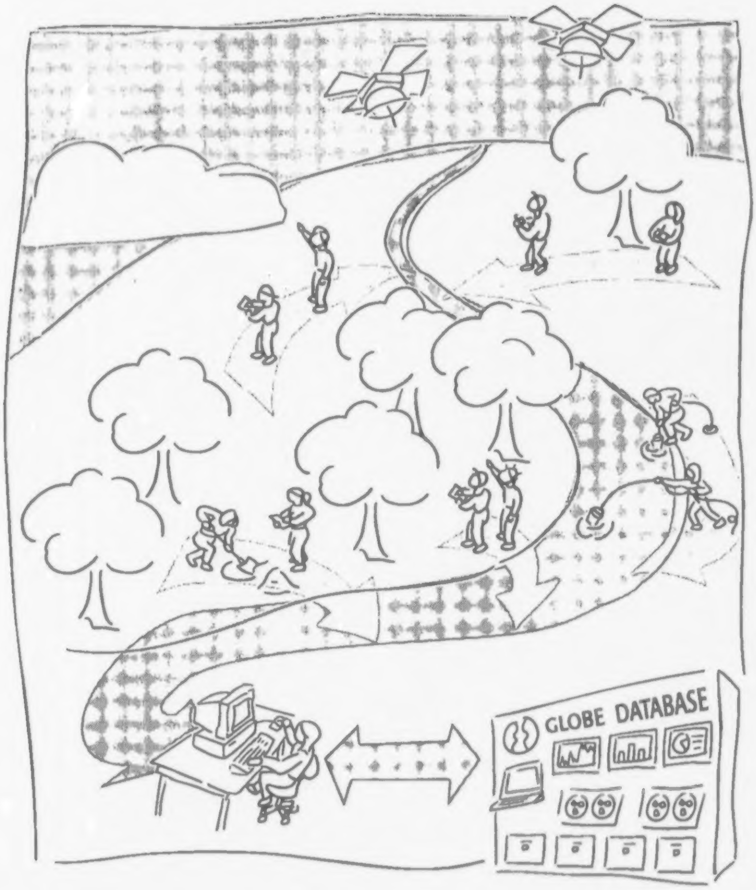
Toolkit


GLOBE DATABASE

for the GLOBE™ Teachers' Guide

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GLOBE Measurements and Their Instruments

GLOBE environmental measurements are in four study areas: Atmosphere/Climate, Hydrology, Land Cover/Biology and Soils. The following pages summarize the current specifications for the instruments. The GLOBE measurements and instruments are differentiated by skill level.

Measurement	Instrument	Skill Level
Atmosphere/Climate		
Cloud Cover/Type	Cloud chart	All
Precipitation, Liquid	Rain gauge	All
Precipitation, Solid	Snow board, Rain gauge, Snow depth pole	All
Precipitation pH	pH indicator paper	Beginning
	pH pen, one pH buffer	Intermediate
	pH meter, three pH buffers	Advanced
Air Temperature Maximum/ Minimum & Current	Maximum/Minimum thermometer, Calibration thermometer, Instrument shelter	All
Hydrology		
Transparency — Deep Water Sites Only	Secchi Disk, 5 m rope	All
Transparency — Surface Water	Turbidity tube	All
Water Temperature	Organic liquid-filled thermometer	All
Dissolved Oxygen	Dissolved oxygen kit	Intermediate, Advanced
Water pH	pH indicator paper	Beginning
	pH pen, one pH buffer	Intermediate
	pH meter, three pH buffers	Advanced
Electrical Conductivity – Fresh Water Sites Only	Total dissolved solids (conductivity) tester, calibration solution	All
Salinity – Brackish and Salt Water Sites	Hydrometer, 500 mL clear plastic graduated cylinder, organic liquid-filled thermometer	All
Salinity Titration Method– Brackish and Salt Water Sites	Salinity kit	Optional Intermediate, Advanced

Measurement	**Instrument**	**Skill Level**
Hydrology (continued)		
Alkalinity	Water alkalinity kit	Intermediate, Advanced
Nitrate	Water Nitrate kit	Intermediate, Advanced
Soil		
Soil Characterization – Field Slope, Horizon Depth, Structure, Color, Consistence, Texture, Carbonates	Clinometer, Camera, Meter stick, Color chart, Sample cans, Other containers, Shovel or Auger	All
Soil Characterization – Lab Bulk Density, Particle Size, Soil pH, Fertility	Drying oven, 100 mL Graduated cylinder, 500 mL clear plastic graduated cylinder, Hydrometer, Thermometer, Dispersing solution, pH paper, pen or meter and pH buffers, Soil NPK kit	All
Soil Moisture	Balance, Meter stick, Drying oven (soils), Sample Cans, Other soil containers, Auger (depth sampling), 50 m tape measure(transect)	All
Gypsum Block Soil Moisture	Soil moisture meter, Gypsum blocks, PVC piping	Optional, Advanced
Infiltration	Dual ring infiltrometer	All
Soil Temperature	Soil thermometer	All
Land Cover/Biology		
Land Cover Mapping	Remote sensing image, MultiSpec software	All
Species Identification	Dichotomous keys	All
Biometry Tree Circumference Tree Height Canopy Cover Ground Cover	Clinometer and densiometer (both may be student-made), 50m tape measure	All
Biometry Grass Biomass	drying oven (plants)	All
Location		
Latitude and Longitude of study sites	Global Positioning System receiver	All

Scientific Instruments for GLOBE Measurements

A number of instruments, supplies, and pieces of equipment are needed to conduct the GLOBE measurements properly. Many of these can be purchased from suppliers while some can be made by students or individuals in the school community. The GLOBE measurements and instruments are differentiated by skill level. In the KIT Column of the following table, B, I, and A indicate that an instrument is included in a beginning (B), intermediate (I), or advanced (A) level kit. Each kit includes the minimum set of instruments which most schools will need to purchase in order to do the GLOBE protocols appropriate for their educational level. O indicates that purchase of this instrument is optional and that it is not included in a kit either because most schools should already have access to one, because schools in an area can reasonably share one instrument, or because the instrument is needed only if certain options within the GLOBE protocols are chosen. M indicates that the instrument can be made at the school or with local assistance.

Instrument	Kit (B,I,A,O,M)	Measurement	Skill Level
Cloud chart	O[1]	Cloud Cover/Type	All
Maximum/Min. Thermometer	B,I,A	Air Temperature - Max/Min. & Current Temperature	All
Calibration thermometer (Organic liquid-filled thermometer)	B,I,A	Air Temperature, Water Temperature, Salinity, Soil Particle Size	All
Instrument Shelter	B,I,A,M	Air Temperature	All
Rain gauge	B,I,A	Precipitation, Liquid, Solid	All
Snow board	M	Precipitation, Solid	All
Snow depth pole	O,M	Precipitation, Solid	All
pH indicator paper	B	Precip. pH, Water pH, Soil pH	Begin.
pH pen	I	Precip. pH, Water pH, Soil pH	Int.
pH 7 buffer	I,A,M	Precip. pH, Water pH, Soil pH	Int., Adv.
pH meter	A	Precip. pH, Water pH, Soil pH	Adv.
pH 4 and pH 10 buffers	A,M	Precip. pH, Water pH, Soil pH	Adv.
Dissolved oxygen kit	I,A	Dissolved Oxygen	Int., Adv.
Water alkalinity kit	I,A	Alkalinity	Int., Adv.
Safety Equipment – Plastic gloves and goggles	I,A	Hydrology: Dissolved Oxygen, Alkalinity, Salinity, Titration Nitrate	Int., Adv.
Total dissolved solids (conductivity) tester	B,I,A[2]	Electrical Conductivity – Fresh water sites only	All
Calibration solution	B,I,A,M[2]	Electrical Conductivity – Fresh water sites only	All

[1] One copy provided to each GLOBE teacher at training

[2] Include in kit only for freshwater sites

Instrument	Kit (B,I,A,O,M)	Measurement	Skill Level
Hydrometer	B,I,A	Soil: Particle Size, Salinity – Brackish/salt water only	All
500 mL clear plastic graduated cylinder	B,I,A	Soil: Particle Size, Salinity – Brackish/salt water only	All
Salinity kit	O	Salinity — Titration Method	Optional, Int., Adv.
Water Nitrate kit	I,A	Hydrology: Nitrate	Int., Adv.
Secchi Disk, Rope	O,M	Transparency — Deep water site only	All
Turbidity tube	M	Transparency Shallow water site	All
Remote sensing image data	See footnote[3]	Land Cover Mapping	All
MultiSpec software	See footnote[4]	Land Cover Mapping	All
Dichotomous keys	O[5]	Species Identification	All
50 m tape measure	B,I,A	Site Layout, Tree Circumference, Tree Height	All
Clinometer	O,M	Tree Height, Slope	All
Densiometer	M	Canopy Cover	All
Plant clippings drying oven	O	Grass Biomass	All
Dutch auger[6]	O	Soil: Profile, Bulk Density, Soil Moisture	All
Sand auger[6]	O	Soil: Profile, Bulk Density, Soil Moisture	All
Peat auger[6]	O	Soil:Profile, Bulk Density, Soil Moisture	All
Bucket auger[6]	O	Soil:Profile, Bulk Density, Soil Moisture	All
Shovel	O	Soil:Profile, Bulk Density, Soil Moisture	All
Camera	O	Soil Profile, Land: Site Layout	All
Meter stick	O	Soil: Depth, Soil Moisture	All
Color chart	B,I,A	Soil Color	All
Distilled white vinegar	O	Soil: Free Carbonates	All
Acid squirt bottle	B,I,A	Soil: Free Carbonates	All
#10 sieve (2 mm mesh)	B,I,A	Soil: Bulk Density, Particle Size	All
Soil drying oven	O	Soil: Moisture, Bulk Density	All
Balance	O	Gravimetric Soil Moisture, Soil Bulk Density	All

[3] Remote sensing image data provided by GLOBE or Country Coordinator

[4] Downloadable from Purdue University http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/Index.html

[5] Choose a dichotomous key appropriate to local vegetation; a generally applicable dichotomous key will be provided to each teacher at training

[6] Select auger appropriate for local soil type

Instrument	**Kit (B,I,A,O,M)**	**Measurement**	**Skill Level**
Soil cans - 15	O,M	Gravimetric Soil Moisture Soil Bulk Density —	All
		Pit or surface method	
Other soil containers	O	Gravimetric Soil Moisture Soil Bulk Density	All
Dispersing solution	B,I,A,M	Soil: Particle Size	All
100 mL graduated cylinder	B,I,A	Soil pH, Bulk Density	All
Soil NPK kit	I,A	Soil Fertility	Int., Adv.
Garden Trowel	O	Gravimetric Soil Moisture	All
PVC Pipe	O,M	Gypsum Block Soil Moisture	Optional Adv.
Gypsum Blocks (4 required)	O	Gypsum Block Soil Moisture	Optional Adv.
Soil Moisture Meter	O	Gypsum Block Soil Moisture	Optional Adv.
Dual Ring Infiltrometer	O,M	Soil: Infiltration	All
Soil Thermometer	B,I,A	Soil: Temperature	All
Global Positioning System receiver	O[7]	Latitude, longitude and elevation	All

[7] Available from GLOBE/UNAVCO

GLOBE Instrument Specifications

Atmosphere/Climate

Cloud Cover/Type - All Skill Levels

Instrument Specifications: Cloud Chart

The GLOBE cloud chart shall display at least one visual example of each of the 10 basic cloud types — cirrus, cirrostratus, cirrocumulus, altostratus, altocumulus, cumulus, nimbostratus, stratus, cumulonimbus, stratocumulus. Sky cover will be visually estimated. The GLOBE Program will provide a cloud chart to each trained U.S. teacher and to each GLOBE Program Country Coordinator.

Precipitation, Liquid - All Skill Levels

Instrument Specifications: Rain gauge

Precipitation will be measured with a clear view plastic rain gauge with a collector that is at least 102 mm in diameter. The rain gauge must be at least 280 mm in height with a scale indicating rain collected of 0.2 mm or less on an inner clear cylinder. It must have the capacity to measure rainfall of 280 mm without overflowing. The shape of the outer part must also be cylindrical, and overflow from the inner cylinder shall be directed to the outer part of the rain gauge. The outer cylinder must be capable of being used in the inverted position to gather a snow sample for measurement of the water content of snow. The rain gauge must be provided with the necessary hardware for installation on a pole. Instructions for siting are provided in the GLOBE Program Teacher's Guide.

Precipitation, Solid - All Skill Levels

Instrument Specifications: Snow Board

The depth of daily snowfall will be measured with a plywood board which is approximately 40 cm X 40 cm x at least 1 cm thick.

Instrument Specifications: Rain Gauge

The rain gauge described in Precipitation, Liquid will be used for this measurement.

Instrument Specifications: Snow Depth Pole

For snow depths less than 1 meter, a meter stick is recommended. When the snow is deeper than one meter, a snow depth pole is used. This can be made from a 2 meter pole by placing two meter sticks end to end on this pole.

Precipitation pH - All Skill Levels

The same instruments described in Hydrology: Water pH will be used for this measurement.

Air Temperature - All Skill Levels

Instrument Specifications: Maximum/Minimum Thermometer

Air temperature shall be measured with a maximum/minimum thermometer. The maximum/minimum thermometer shall be readable only in degrees Celsius, with maximum and minimum scales marked in increments of 1.0° C, and the scales must be capable of supporting temperature estimations to the nearest 0.5° C. The thermometer must be in a sturdy protective case, and be provided with the necessary hardware for installation. It must be factory calibrated to an accuracy of +1.0° C. Both scales must be adjustable for calibration. Each scale must be clearly marked to indicate Celsius, and have indicators such as "+" and "-" on each scale to indicate direction of increasing and decreasing temperature. In addition, each scale must be clearly marked to identify which scale is maximum and which is minimum. Siting and installation instructions are provided in the GLOBE Program *Teacher's Guide*.

Instrument Specifications: Calibration Thermometer

The maximum/minimum thermometer will be calibrated with a second thermometer which is an organic liquid-filled thermometer with a temperature range of -5° C to 50° C. The thermometer must be factory calibrated and tested with standards traceable to N.I.S.T (The National Institute of Standards and Technology - United States) to an accuracy of +0.5° C, with 0.5° C scale divisions. It must be supplied with a metal jacket with holes at the bulb end to allow for circulation and a hole at the top by which to hang the thermometer in the instrument shelter for calibration of the maximum/minimum thermometer.

Instrument Specifications: Instrument Shelter

An instrument shelter is required to house the maximum/minimum thermometer and the calibration thermometer to assure scientifically usable air temperature measurements. The instrument shelter must be constructed of a material with a thermal insulation value which equals or exceeds that of seasoned white pine wood (1.8 cm thick). It must be painted white with exterior grade paint. The shelter must be vented, and be large enough to allow air circulation around the thermometer. The inside dimensions must be at least 45 cm high, 22.8 cm wide, and 15.25 cm deep. The shelter must have a hinged door on the front, be louvered on the front and sides, and have holes in the bottom and holes at the uppermost part of the sides to increase ventilation if the louvers do not extend to the top of the sides. The door must contain a lock. The instrument shelter must be mountable onto a wall or post. The top of the shelter must slope downward toward the front. The parts of the shelter must be securely fastened to each other, either using screws or with nails and glue. Joints must be sealed with weather resistant caulking compound.

Hydrology

Water Temperature: - All Skill Levels

Instrument Specifications: Organic liquid-filled thermometer

The calibration thermometer described in Air Temperature will be used for this measurement.

Transparency - All Skill Levels

Instrument Specifications: Secchi Disk Apparatus (for deep water sites only)

5 m length of rope and a disk with a diameter of 20 cm. The disk shall be colored with paint or other appropriate means such that alternate quadrants of each side are black and white. The disk must be made so that it will not be disfigured or damaged by repeated immersion in water, including sea water. It must be weighted such that it remains horizontal while it is lowered by the rope in the water.

Instrument Specifications: Turbidity Tube (for surface water)

Clear plastic tube, approximately 1.2 m long and 4.5 cm diameter with a white cap that fits securely on the end of the tube. The end cap must display a pattern consisting of alternating black and white quadrants on the side that is viewed by looking down the tube.

Water pH - All Skill Levels

Note: The instrument requirements for this measurement vary according to skill level. Please select the appropriate instrument for your students.

Skill Level - Beginning

Instrument Specifications: pH Paper

The pH of standing water at this skill level will be measured with pH paper which can be purchased in strips or rolls. The pH paper must have +1.0 pH unit accuracy, with a range pH 1 to pH 14.

Skill Level - Intermediate

Instrument Specifications: pH Pen

The pH of standing water at this skill level will be measured with a pH pen. The GLOBE instrument must have an accuracy of +0.2 pH units with a range of pH 1 to pH 14. The operating temperature range must be 0° C to 50° C. The pH pen must be capable of being calibrated using a known pH buffer solution.

Skill Level - Advanced

Instrument Specifications: pH Meter

The pH of standing water at this skill level will be measured with a pH meter. The pH meter must have an accuracy of +0.1 pH unit, and a range of pH 1 to pH 14, at temperatures from 0° C to 50° C. The device shall automatically compensate the reading when it is placed in solutions of differing temperature. The pH meter must be capable of being calibrated automatically using known pH buffer solutions.

Skill Level - Intermediate, Advanced

Instrument Specifications: Buffers

pH buffer solutions are required to calibrate the pH pen and meter. The buffer solutions should have a value of pH 4.0, pH 7.0 and pH 10.0; only the pH 7.0 buffer is required for the pH pen at the intermediate skill level.

Dissolved Oxygen - Intermediate, Advanced Skill Levels

Instrument Specifications: Dissolved Oxygen Kit

A dissolved oxygen test kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Enables measurement of dissolved oxygen with an accuracy of at least +/- 1 mg/L
- Contains all the chemicals and special containers to perform this measurement based on the Winkler titration method. This method is described in *Standard Methods for the Examination of Water and Wastewater*, 19th edition, 1995, a publication of the American Public Health Association, Washington, DC.
- Contains clear instructions for using the kit to make this measurement using a procedure based on the Winkler titration method.

Alkalinity - Intermediate, Advanced Skill Levels

Instrument Specifications: Water Alkalinity Kit

A water alkalinity kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Enables measurement of total alkalinity with an accuracy of at least 6.8 mg/L as $CaCO_3$ (low range, under 136 mg/L), and 17 mg/L as $CaCO_3$ (high range, above 136 mg/L).
- Contains all chemicals and containers needed to perform the alkalinity titration, including: 1) Bromocresol green-methyl red indicator and scoop for adding the required amount to the

sample, 2) sulfuric acid for titration, and method of delivering acid to sample to achieve the required accuracy, 3) measuring containers and bottles for titration. This method is described in 19th edition, 1995, a publication of the American Public Health Association, Washington, D.C.

- Contains clear instructions for using the kit to make this measurement, based on acid titration to a Bromocresol green-methyl red end point.
- Plastic gloves and safety goggles

Instrument Specifications: Safety Equipment

Plastic gloves and safety goggles must be used in making this measurement.

Electrical Conductivity (for fresh water sites) - All Skill Levels

Instrument Specifications: Electrode-type total dissolved solids tester (conductivity meter)

This device shall measure electrical conductivity of liquid solutions using two metal electrodes separated by a fixed distance. The device shall be designed to be hand-held, and battery powered, with no electrical power cord attached. The device shall employ a method to automatically compensate the indicated conductivity value relative to changes in the temperature of the solution. The measurement range shall be at least from 0-1990 microSiemens/cm, with a resolution of 10 microSiemens/cm, an accuracy of +/- 2% full scale, and an operating temperature of 0-50 C. The device shall be capable of calibration using a standard solution.

Instrument Specifications: Calibration Standard

A solution of KCl and water or NaCl and water that has a conductivity of about 450 microSiemens (225.6 mg/L KCl or 215.5 mg/L NaCl).

Salinity (for brackish and salt water sites) -All Skill Levels

Instrument Specifications: Hydrometer Method

The same instrument described in Soil Particle Size will be used for this measurement.

A 500 mL clear plastic cylinder and an organic liquid-filled thermometer for use with the hydrometer are required. The 500 mL cylinder for Soil Particle Size may be used. The calibration thermometer for Air Temperature may be used.

Instrument Specifications: Salinity Titration Method - Optional, Intermediate, Advanced Skill Levels

A salinity kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Range: 0 - 20 parts per thousand (ppt)*
- Smallest increment: 0.4 ppt
- Method/chemistry: chloride titration
- Approximate number of tests: 50
- Contains clear instructions for using this kit to make this measurement, based on the chloride titration method.

*Titrator must be refillable for use in higher salinity waters.

Nitrate - Intermediate, Advanced Skill Levels

Instrument Specifications: Water Nitrate Kit

A nitrate kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Range: 0 - 10 ppm NO_3-N
- Smallest increment: 0.05 ppm NO_3-N for the range 0 - 1 ppm NO_3-N; 0.5 ppm NO_3-N for the range 1 - 10 ppm NO_3-N
- Method/chemistry: cadmium reduction
- Approximate number of tests: 50
- Contains clear instructions for using this kit to make this measurement, based on the cadmium reduction method.

Soil Characterization

Soil Slope - All Skill Levels

Instrument Specifications: Clinometer

The clinometer described in Land Cover: Tree Height will be used for this measurement.

Soil Profile - All Skill Levels

Instrument Specifications: Camera

It is assumed that a camera with color film is available locally.

Instrument Specifications: Meter Stick

A durable ruler with gradations every cm and mm.

Soil Structure - All Skill Levels

Instrument Specifications: None

Color - All Skill Levels

Instrument Specifications: Color Chart

A soil color chart designed especially for the GLOBE Program can be purchased. It contains at least 200 colors and uses the Munsell System of Color Notation. This flip chart is weather-resistant and has large color chips which are edge-mounted for ease of reading. The color range includes all hues found in the full set of International soil colors, yet provides a selected set of values and chroma to aid color identification for students. Manufacturers who wish to prepare another version should contact the GLOBE Program for the complete list of colors.

Soil Consistence - All Skill Levels

Instrument Specifications: None

Soil Texture- All Skill Levels

Instrument Specifications: None

Free Carbonates - All Skill Levels

Instrument Specifications: Vinegar

Distilled white vinegar. Household vinegar may be used.

Instrument Specifications: Acid Squirt Bottle

A bottle capable of safely holding at least 200 mL of acid is required.

Sample Preparation for Bulk Density, Particle Size, Soil pH, and Fertility Protocols - All Skill Levels

Instrument Specifications: Sieve

Number 10 sieve with 2 mm mesh attached to a frame.

Soil Bulk Density - All Skill Levels

Instrument Specifications: Graduated Cylinder - 100 mL

Glass graduated cylinder with a capacity of 100 mL marked in 1 mL or smaller divisions, with graduations covering at least the range from 10 mL to 100 mL.

Instrument Specifications: Balance and Augers

The same balance and auger used for Gravimetric Soil Moisture will be used for Bulk Density.

Instrument Specifications: Soil Sample Cans and Other Soil Containers

Cans and containers should meet the same specifications as given for these items for Gravimetric Soil Moisture

Soil Particle Size - All Skill Levels

Instrument Specifications: Hydrometer

The hydrometer used should meet the following requirements:

- Calibrated to specific temperature for water and sample (e.g. 15.6 C / 15.6 C
- Range (specific gravity / no units): 1.0000 - 1.0700
- Smallest increment (no units): 0.0005

Instrument Specifications: Thermometer

The Calibration Thermometer described in Air Temperature will be used for this measurement.

Instrument Specifications: 500 mL Clear Plastic Graduated Cylinder

One 500 mL capacity plastic graduated cylinder, marked at least at the 500 mL level. Cylinder must be clear plastic, not frosted plastic and not glass. Instrument Specifications: Dispersing Solution Sodiumhexametaphosphate powder or a 10% solution of either sodiumhexametaphosphate or a detergent that does not produce suds.

Soil pH - All Skill Levels

Instrument Specifications: pH measurement devices

The same instruments described in Hydrology: Water pH will be used for this measurement.

Instrument Specifications: Graduated Cylinder - 100 mL

The same instrument as described in Bulk Density will be used for this measurement.

Soil Fertility - Intermediate, Advanced Skill Levels

Instrument Specifications: Soil NPK (Macronutrients) Kit

The test kit must:

- Contain unit-dose reagents and containers needed to extract soil nutrients from 50 samples and to perform 50 tests of each: soil nitrogen; soil phosphorus; and soil potassium.

- Employ methods based on the Spurway extraction method, the zinc reduction/chromotropic acid method for nitrogen, the ascorbic acid reduction method for phosphorus, and the sodium tetraphenylboron (turbidimetric) method for potassium.
- Contain clear instructions, including diagrams, for using the kit.
- Contain a water resistant color chart for interpreting the results of colorimetric tests and a turbidity chart for the turbidimetric test.

Soil Moisture and Temperature

Gravimetric Soil Moisture - All Skill Levels

Instrument Specifications: Balance

This balance must have the capacity to weigh 300 grams with an accuracy of +/- 0.1 gram. It can be either mechanical or electronic. It is assumed that a balance is available locally, for example in a high school science laboratory.

Instrument Specifications: Drying Oven (soils)

Drying oven capable of holding a temperature of 95 C - 105 C for at least 10 hours or a temperature of 75 C - 95 C for 24 hours. The oven must be ventilated, and have interior dimension of at least 25 cm x 30 cm x 25 cm. It is assumed that an oven is available locally, for example in a high school science laboratory.

Instrument Specifications: Microwave Drying Oven

Any microwave oven compatible with school use.

Instrument Specifications: Soil Sample Cans

15 round sample tins. A metal container with a diameter 7 cm, and height 5 cm, with a removable cover is appropriate as are small round, cleaned food cans. Cans must be capable of having a small hole punched in their bottoms.

Instrument Specifications: Other Soil Containers

15 containers large enough to have soil samples transferred into them directly from an auger without loss of sample. Glass jars, plastic food containers with lids, or other containers that can be covered and that can hold the soil samples while they are dried in the drying oven selected.

Instrument Specifications: Dutch Auger For Combination Soils

Dutch (or Edelman) auger for combination soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Instrument Specifications: Dutch Auger For Sandy Soils

Auger designed for sandy soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Instrument Specifications: Bucket Auger

Bucket (or Riverside) auger designed for hard and brittle soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Instrument Specifications: Peat Auger

Auger designed for peat soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Gypsum Block Soil Moisture - Optional, Advanced Skill Level

Instrument Specifications: Gypsum Blocks

Cast gypsum blocks: approx. 25 mm high x 20 mm diameter; in which concentric stainless steel mesh electrodes are embedded; 1.5-2.0 meter insulated lead wire soldered to electrodes

Instrument Specifications: Soil Moisture Meter

Hand-held AC conductivity meter designed for use with gypsum blocks (described above); push button calibration/compensation and push button digital reading. Conductivity may be normalized to between 0 and 100. The unit must have two terminals which enable attachment and removal of electrical conductor wires on a daily basis. The unit must be battery powered and be capable of being hand-held and used in remote locations.

Instrument Specifications: PVC Piping

The PVC pipe assists in placing the gypsum block sensors in the ground. It should be 90 cm in length and approximately 2 cm in diameter. Additional PVC piping is required to mark the location of the sensors. These should be 23 cm long with a diameter of approximately 5 cm. Four pieces of this material are required.

Infiltration — All Skill Levels

Instrument Specifications: Dual Ring Infiltrometer

Two concentric metal cylinders. The inner one must have a diameter of 10 cm to 25 cm. The outer one must have a diameter at least 10 cm larger than the inner cylinder. Both cylinders should be 10 to 15 cm high and open at both ends. Steel cans may be found which will work for this apparatus.

Soil Temperature- All Skill Levels

Instrument Specifications: Soil thermometer

A 11 cm to 20 cm stainless steel probe, heavy-duty construction dial or digital thermometer with a range of at least -10 to 50 degrees C (Celsius scale required) and an accuracy of 1% full scale (over a range of no more than 200 degrees C) or better is required. The sensor should be in the bottom third of the probe. The sensor should give stable readings after less than 60 seconds in an isothermal bath. Batteries, if required, should be included. The sensor should be adjustable with the calibration procedure and achievable accuracy clearly stated. Dial thermometers must be sealed against fogging and be covered with shatterproof glass or plastic. Scale graduations of 1.0 degrees C and 0.1 degrees C are preferred for dial and digital thermometers, respectively. Glass stem thermometers are NOT acceptable.

Land Cover/Biology

Land Cover - All Skill Levels

Instrument Specifications: Landsat Thematic Mapper (TM) Image, MultiSpec software.

The GLOBE Program will provide a TM image to all US schools. MultiSpec software is available for downloading from the Internet.

Species Identification - All Skill Levels

Instrument Specifications: Dichotomous Keys

Dichotomous keys for tree identification are not available from a central supplier; they need to be acquired locally.

Biometry
Layout of the Biology Site - All Skill Levels

Instrument Specifications: Tape Measure

50 m tape, graduated one side, marked in 2 mm or smaller units.

Tree Circumference - All Skill Levels

Instrument Specifications: Tape Measure

The tape measure described in Layout of the Biology Site will be used for this measurement.

Tree Height - All Skill Levels

Instrument Specifications: Tape measure

The tape measure described in Layout of the Biology Site will be used for this measurement.

Instrument Specifications: Clinometer

The clinometer may be made by students from plans in the GLOBE Teacher's Guide, or may consist of a moveable dial within a metal case and lens viewer. For the moveable dial version, the scale must be graduated from 0-90° in 1° units.

Canopy Cover - All Skill Levels

Instrument Specifications: Densiometer

The densiometer may be made by students according to instructions in the GLOBE Teacher's Guide.

Ground Cover - All Skill Levels

Instrument Specifications: none

Grass Biomass - All Skill Levels

Instrument Specifications: Balance

This balance must have the capacity to weigh 300 grams with an accuracy of +/- 0.1 gram. It can be either mechanical or electronic. It is assumed that a balance is available locally, for example in a high school science laboratory.

Instrument Specifications: Drying Oven (plants)

This oven must be capable of holding samples at 50-70 C for up to two days and must be ventilated to allow moisture to escape. The interior dimensions of the oven must be at least 25 cm x 30 cm x 25 cm. It is assumed that an oven is available locally, for example in a high school science laboratory. The oven should be designed for drying biological samples or food and should not be a conventional cooking oven, which could present a fire hazard in this application.

GPS

Latitude, Longitude and Elevation of GLOBE Study Sites - All Skill Levels

Instrument Specifications: Global Positioning System (GPS) Receiver

The instrument must be capable of:

- Expressing latitude and longitude in whole degrees, minutes and decimal minutes to the nearest 0.01 minutes and
- Displaying time on screen in units of UT hours, minutes, and seconds,
- Using the WGS-84 map datum, and
- Displaying elevation in meters.

US Schools may request to borrow a unit from UNAVCO at:

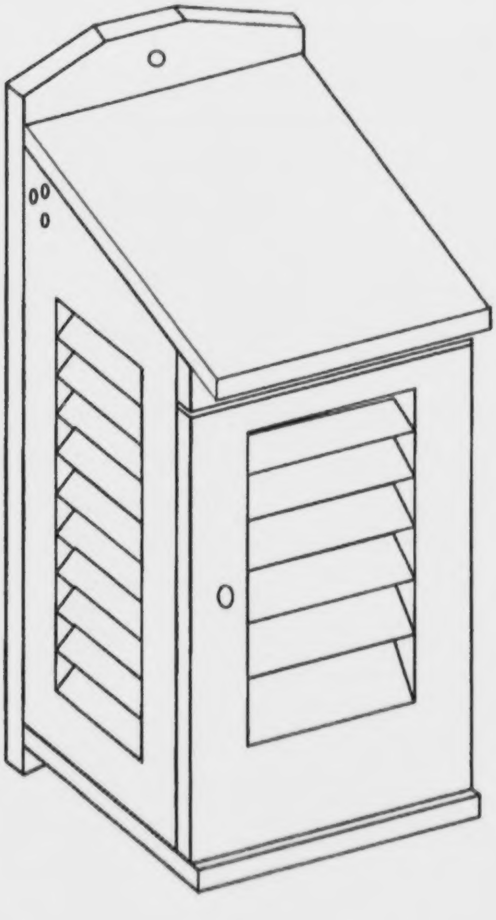
UNAVCO/UCAR
PO Box 3000, UN 393
Boulder, CO 80307-3000
Tel. (303) 497-8000
Fax. (303) 497-7857

Non-US Schools should contact their GLOBE Country Coordinator for information regarding GPS receivers.

Instrument Shelter Plans

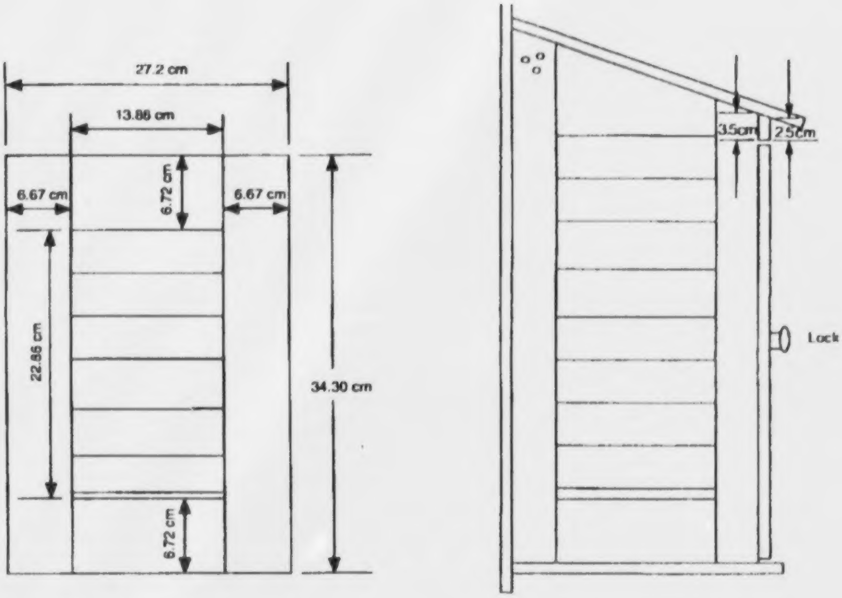
The GLOBE Instrument Shelter should be constructed of 1.9 cm thick White Pine or similar wood and painted white, inside and out. A lock should be installed to prevent tampering with the instruments. Mounting blocks should be installed on the interior to insure that the max/min thermometer does not touch the back wall. The door is hinged on the side. This is not shown in the diagram. The parts should be screwed together or glued and nailed. The plans are specified in metric units, however, the original dimensions were in English units.

Figure TK-1



Instrument Shelter Plans

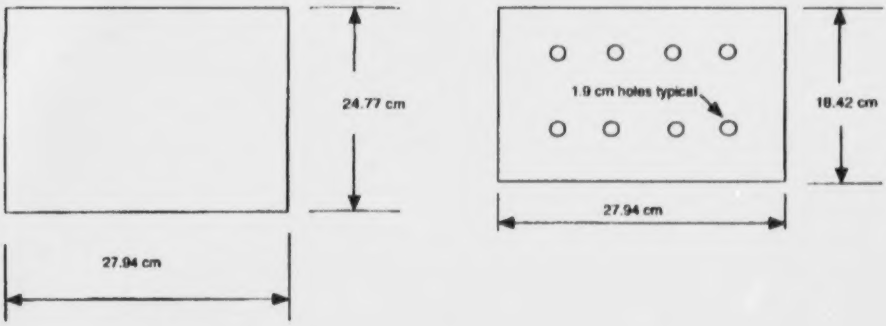
Figure TK-2


27.2 cm
13.86 cm
6.67 cm
6.72 cm
6.67 cm
22.86 cm
34.30 cm
6.72 cm
3.5cm
2.5cm
Lock

Front Door

Side View

Note: Louvers are 0.64 cm thick and 4.13 cm wide

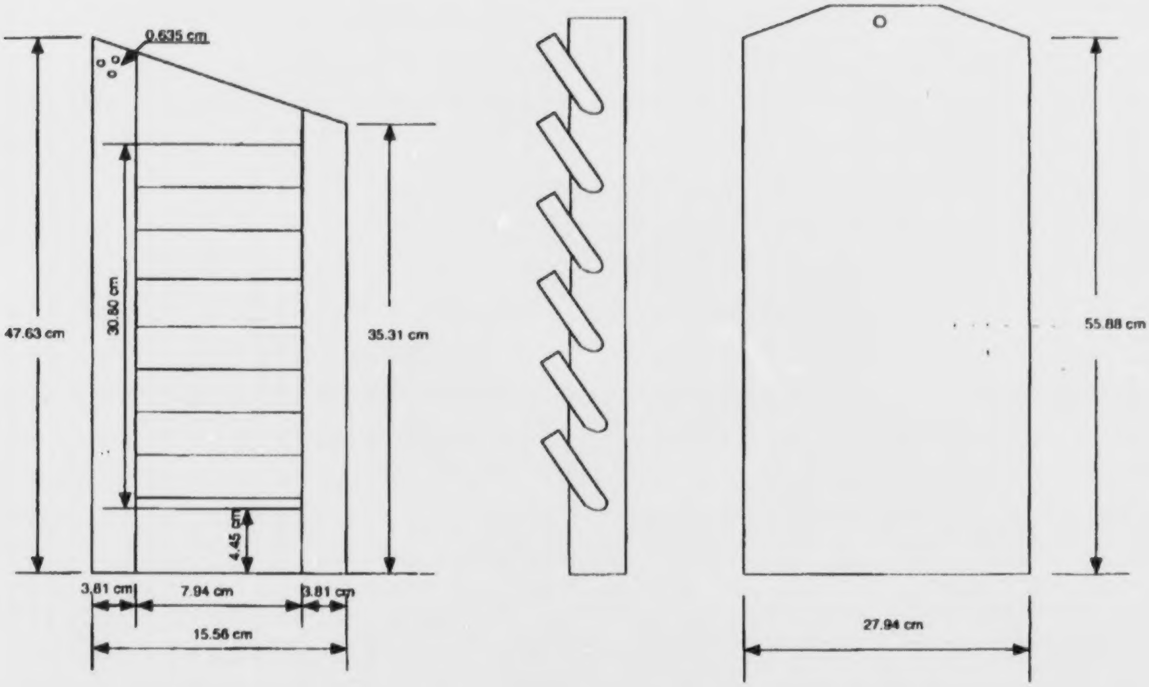

24.77 cm
27.94 cm
1.9 cm holes typical
18.42 cm
27.94 cm

Roof

Bottom

Instrument Shelter Plans

Figure TK-3


0.635 cm
47.63 cm
30.80 cm
35.31 cm
4.45 cm
3.81 cm
7.94 cm
3.81 cm
15.56 cm
55.88 cm
27.94 cm

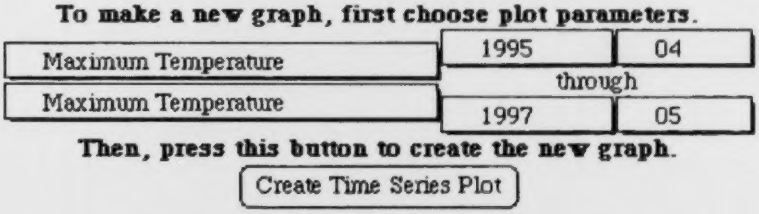
Side panel

Louvre Detail

Back

Using the GLOBE Graphing Tool

1. Open the GLOBE Visualizations location on the GLOBE Student Server.
2. Click on "What's New."
3. Click on "try out new system."
4. Click on "GLOBE Graphs - Time Plot of Student Data."
5. Select one of the methods to call up your school or another school of interest. If you use Method 2: Latitude-Longitude Search, type in the desired latitude or longitude (or both). If you leave one box or the other empty, it will search only on the requested coordinate. North latitudes and East longitudes are denoted by positive values. South latitudes and West longitudes are denoted by negative values. Therefore, 40N 70W would be entered as 40 and -70. To determine the size of the search swath, open the "Find the Schools Within" menu. One degree is roughly equivalent to 100 km. A wide swath can generate a large list of GLOBE sites which may cause your computer to freeze. If this happens, restart and select a narrower swath.
6. Click on school(s) of interest. You can create the following types of graphs:
    - 1 parameter for 1 school
    - 2 parameters for 1 school
    - 1 parameter for 2 schools
7. Click on "Plot Time Series" to begin the graphing procedure.
8. The following boxes enable students to select the parameter(s) and time period for the graph.



To make a new graph, first choose plot parameters.

Maximum Temperature

Maximum Temperature

1995 04 through 1997 05

Then, press this button to create the new graph.

Click on a box and select from the menu of choices. Click on the "Create Time Series Plot" button to generate the graph. The program sets the y-axis values to fit the data range. Different graphs of the same parameter from different schools may have different intervals on the y-axis.

Note: This tool will be upgraded periodically, and its presentation and capabilities will be enhanced.

Manual Classification

A Tutorial for the Beverly, MA , Image

The following tutorial is provided as an example of how a manual interpretation land cover map is made for the Beverly, MA, TM image. See Figure TK-4. After completing this tutorial as a training exercise, each step presented should also be done by your students, but using the TM image of your own area (both the original 512 X 512 pixel TM image, and color enlargements made by the teacher and distributed to groups of students). Figure TK-4 shows a false-color infrared image of a 101 by 101 pixel (3 km x 3 km) enlargement of the Beverly, MA image. The enlarged area is Manchester-by-the-Sea, MA, and will be used to illustrate the process of performing a "manual" land cover classification. Note that water and vegetation types are much more readily distinguished if the false color IR image is used to make the land cover map.

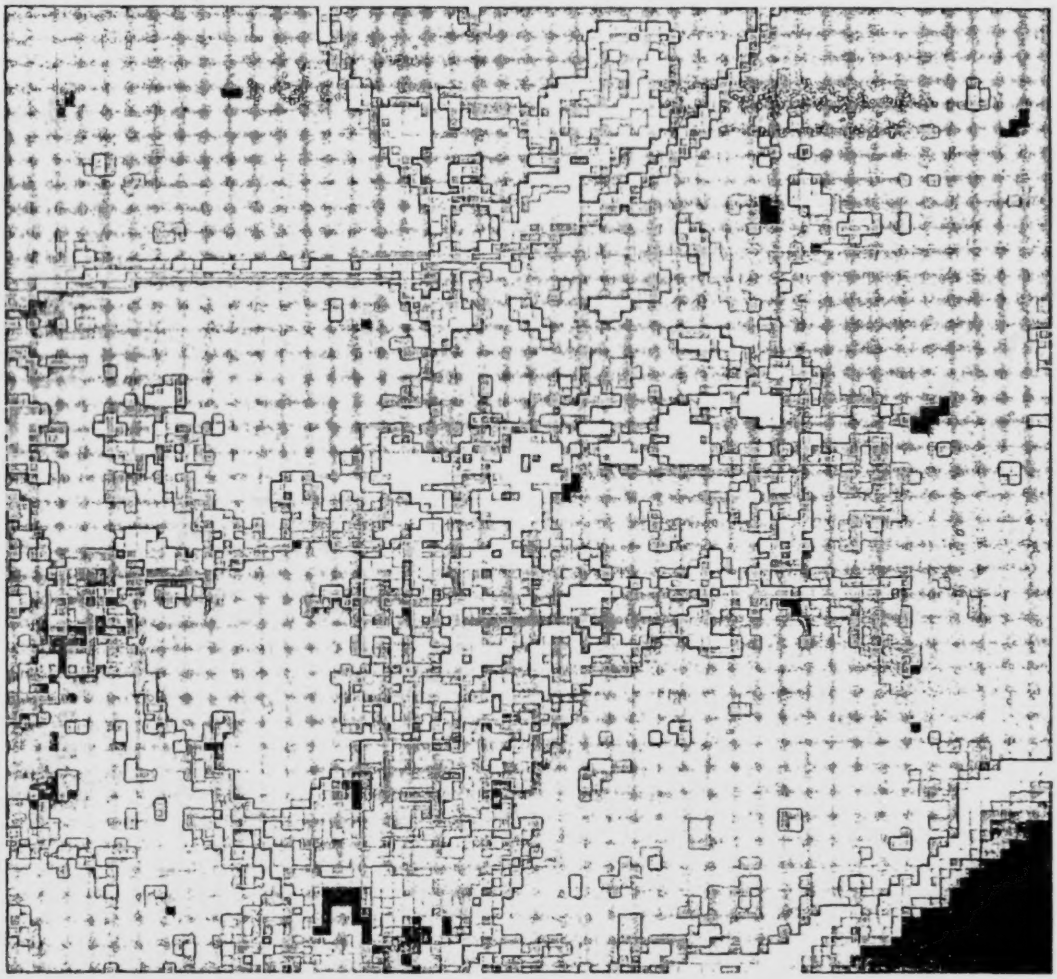
The following steps are used in the manual interpretation method:

1. Select the Landsat TM image to be mapped (the 3 km X 3 km Manchester-By-The-Sea false color IR print provided as Figure TK-4.) In the false color IR image, actively growing green vegetation will appear red (hardwoods and fields are bright red, evergreens are dark red to black), water is black, while urban areas and bare soils are blue. This image has been enlarged from the original 512 X 512 pixel (15 km X15 km) image of Beverly, MA, to produce Figure TK-4. You may choose to do this using an enlarging color xerox, or you may need to arrange to print copies from your Landsat file, using MultiSpec. You may have four or more small groups of students working on different enlarged portions of the original 512 X 512 pixel image of your area.
2. Overlay an 8.5 X 11 inch sheet of clear plastic on top of the colored print of the image, using tape to hold it firmly in place. Once the overlay is in place, mark the location of the image edges on the overlay so that it can be placed in exactly the same position if it is removed. This will also allow you to place the overlay on either the true color image or the false color IR image in order to take advantage of the discrimination capabilities of each type of image.
3. The classification process involves carefully outlining the different land cover types seen on the image, using either colored crayons or felt-tip marking pens. Use different colors to represent each different land cover class, and assign to each the appropriate number for its specific MUC Level 4 land cover classification (MUC is the Modified UNESCO Classification system. It can be found in the *Land Cover/Biology Investigation*.)

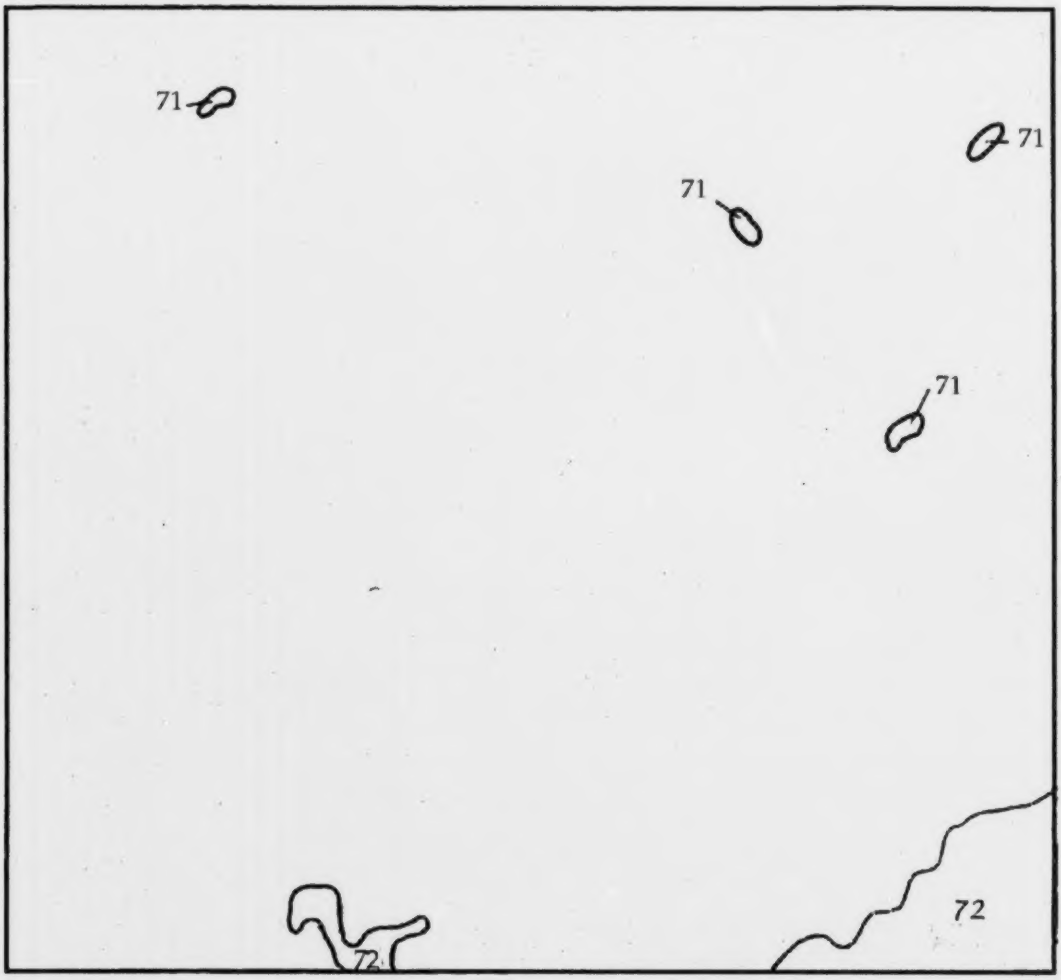
- Outline the water bodies as shown in Step 1 using the MUC Level 2 class 72 for Marine, 63 for tidal river, and 64 for a lake (note that in some cases, no Level 3 or Level 4 categories have been developed for the MUC system).
- Outline the urban/transportation features next, and shown in Step 2. The MUC category 93 (transportation) is assigned in this case.
- Outline urban features next, as shown in Step 3. These features include commercial and industrial (#92); residential (#91); and a golf course, labeled "other" (#94).
- Finally, outline the various forest vegetation types, such as 0192 to indicate evergreen forests typical of eastern Massachusetts, 0222 for mixed hardwoods and softwoods, and 0231, for mainly hardwoods (deciduous), as shown in Step 4.

The final product (Step 4) represents a land cover map for the Manchester-By-The-Sea, MA, area. In this example, it will not be possible for you and your students to field check any of the questionable cover types (ie, the gravel pit marked with a question mark (?) in Step 3). If your students are not sure of a specific area or class for your own images, have a discussion as to what the class might be and ask a student living near the area to provide a ground assessment on the way to or from school. This activity is likely to take several class periods to complete. Ask your students to be as careful and specific as possible in outlining and assigning classes to the various patterns seen on their images. Good Luck!!!

Figure TK-4: Beverly Landsat Scene



Step 1

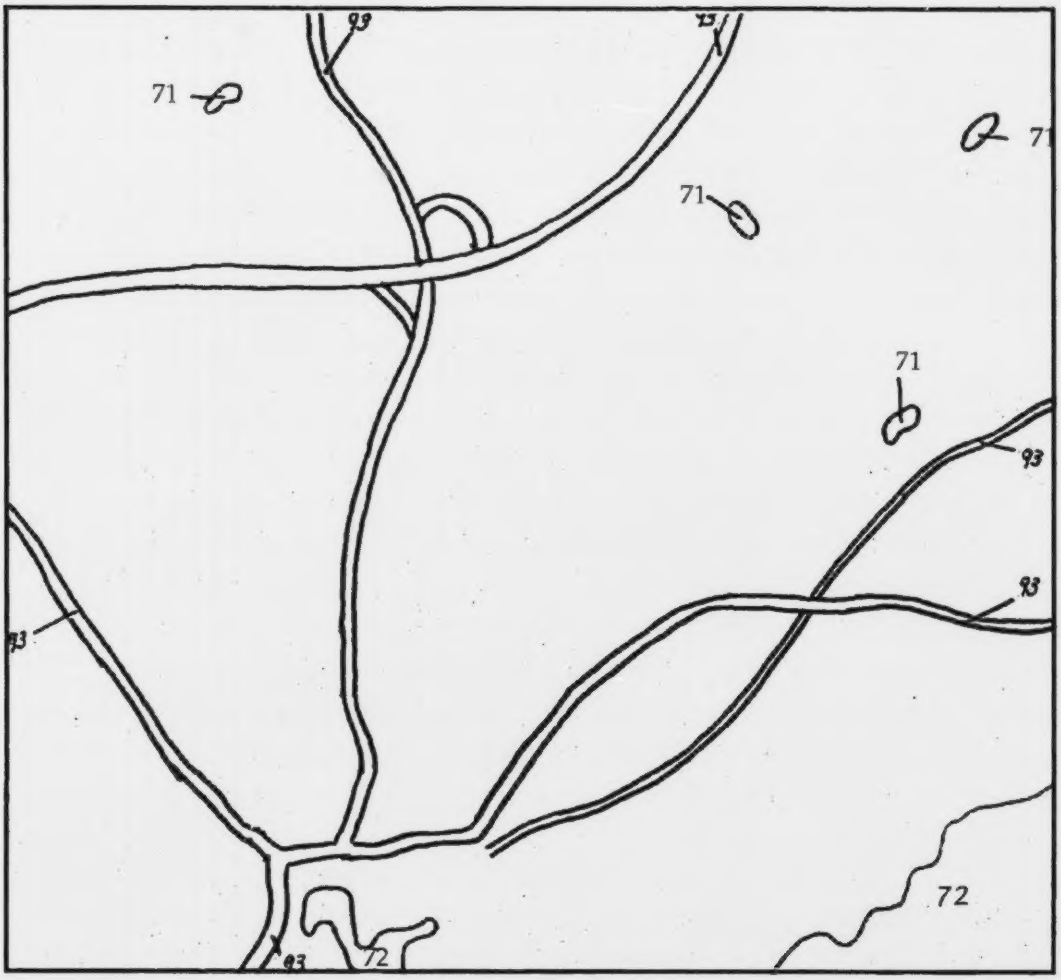

71
71
71
71
72
72

Step 1: Areas of water are outlined

72=marine

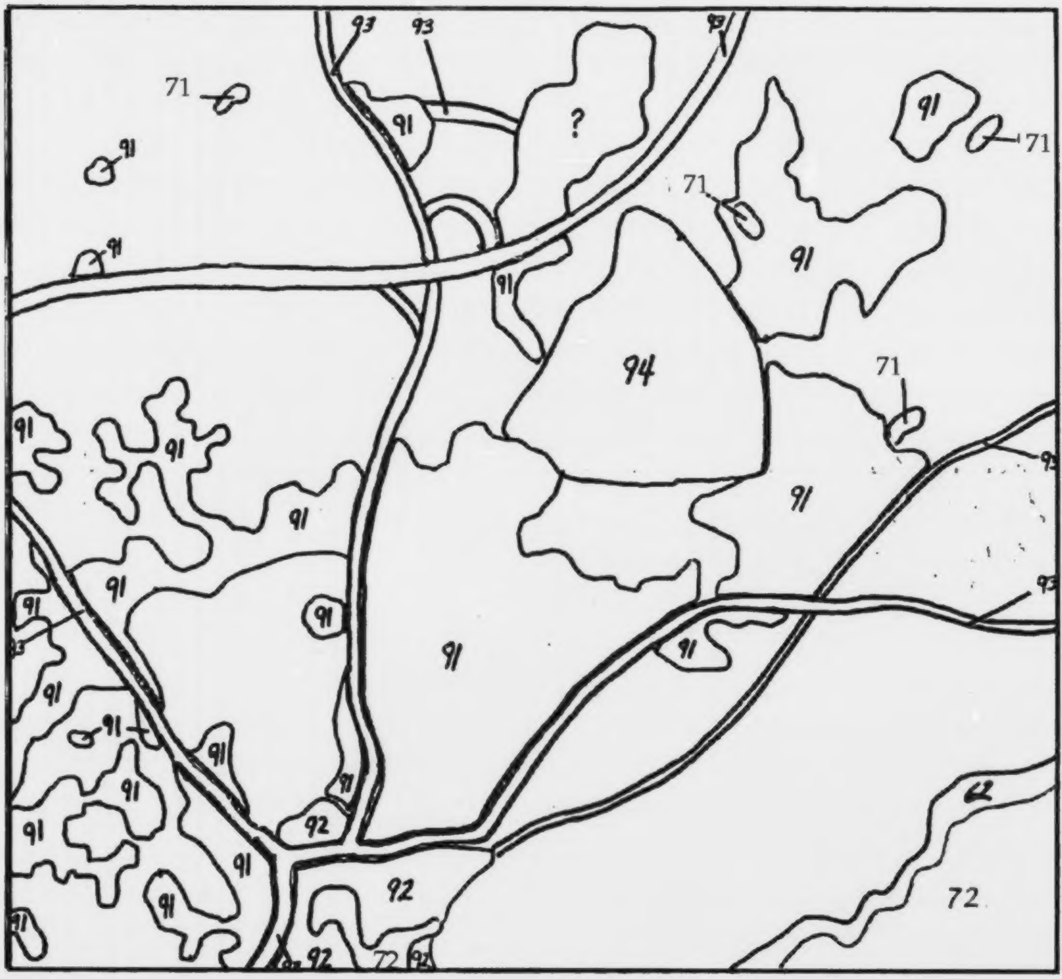
71=freshwater

Step 2


93
73
71
71
71
71
93
93
93
72
93
72

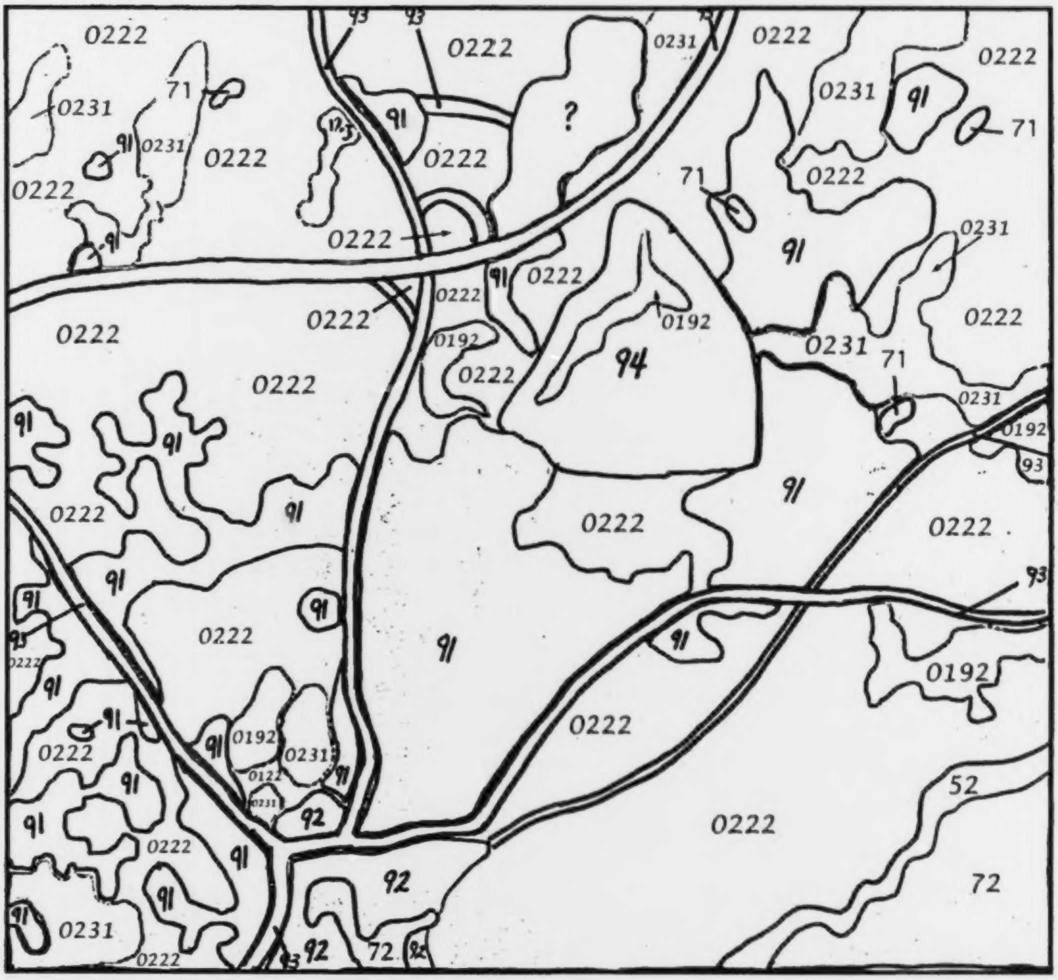
Step 2: Transportation features are outlined (roads, railways, etc)

Step 3


93
93
93
71
91
?
91
71
91
71
91
91
91
94
71
91
91
91
91
91
93
91
91
91
91
93
91
91
91
91
91
91
92
62
91
91
92
72
91
92
72
92

Step 3: Outline Urban Features (residential areas, commercial and industrial areas, etc.) Note that the gravel pit (? area) looks like commercial but needs to be ground checked.

Step 4



0222
0231
71
91
0222
93
0222
0231
0222
0222
0222
?
0231
71
0222
91
0222
0231
0222
0222
0192
94
0192
0222
0231
71
91
0222
0231
0192
93
0222
93
0192
52
0222
72
92
72
0231
0222

Step 4: Vegetated areas are outlined for the final step.

0192=Evergreens

0222=Mixed hardwood/softwood-mainly deciduous forest with some evergreens

0231=Hardwood(deciduous)-mainly deciduous forest without evergreens

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Introduction to the MultiSpec© Program

Funded by a NASA grant, David Landgrebe, in conjunction with the Purdue Research Foundation, developed the software program **MultiSpec (© Purdue Research Foundation)** to allow for the investigation of the use of satellite imaging in an educational setting. Although originally intended for university use, MultiSpec has proven to be a highly motivational educational computer program at the elementary through high school level. MultiSpec is now licensed through the Purdue Research Foundation for universal use. This software is provided to you for use in your classroom.

EOSAT, a corporation licensed by NASA, processes and distributes 32,930 square kilometer Landsat scenes. Because processing of scenes from data transmitted directly from satellites is extremely complex, the scenes currently cost about $4400. Scenes, in the form they are distributed, require sophisticated computer equipment to process further into the specific format suitable for the work being done by the researcher. The images you received are 9.3 mile by 9.3 mile five band subsets of scenes that have been purchased for educational purposes by universities or research institutions. Their size is dictated by 3.5" high density floppy disk space limitations. Each image you received fits on one such disk. You may be able to acquire free local images from sources in your state. To do this, check with your state university and try to locate people who are doing research with Landsat satellite images. You would ask them for a subset of a scene in ASCII format. They may be willing to download the data from their workstations to MS-DOS format and then you can copy that file to an IBM-compatible computer (hereafter referred to as a PC) or to a Macintosh computer if it has a universal drive that reads MS-DOS formatted disks.

Computer requirements for using MultiSpec©.

To use the MultiSpec computer program on a Macintosh computer, you will need a hard drive, 2 megabytes (2000K) of random access memory (RAM), and a color monitor. This configuration will allow the selection of 8-bit color. In order to use the 24-bit color option, you will need a minimum of 4 megabytes (4000K) of RAM. Twenty-four bit color allows for better distinguishing of features (feature definition) in an image display. If your Macintosh computer has virtual memory capability, and you feel comfortable using it, you may want to turn it on. Virtual memory is not a requirement.

OR,

To use the program on a PC, you will need a 386, 486, or Pentium processor, a hard drive with the MS-Windows 3.0 or newer program installed, and a color monitor. For the best image display an SVGA monitor is recommended.

Acquiring the MultiSpec© Software

The program software and documentation can be downloaded over the Internet at the following URL:

http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/

or ordered via E-Mail at the following:

landgreb@ecn.purdue.edu

There are four versions of the program; one is for use on a Power Macintosh/Macintosh computer with a math coprocessor/FPU, one is for use on a Macintosh computer without a math coprocessor, one is for use on a PC with a math coprocessor, and the last is for use on a PC without a math coprocessor. If you do not know whether or not your Macintosh computer has a math coprocessor/FPU acquire both versions. It should not be a problem for PC users to know if a coprocessor is installed.

The instructions for installing and using MultiSpec© are provided separately for the Macintosh computer and for the PC computer. The Macintosh instructions follow immediately; the PC instructions begin on page Toolkit-63.

Installing MultiSpec© on Your Macintosh Computer

Note: If you lack experience using a Macintosh computer, the author recommends you take a few minutes to get accustomed to using a Macintosh. One of the easiest methods is to use the "Learning to Use Your Macintosh" tutorial program that came with your computer.

If you are an experienced user briefly read the following sections that discuss installation and memory options so that you copy the appropriate files to your hard drive and proceed to page 9.

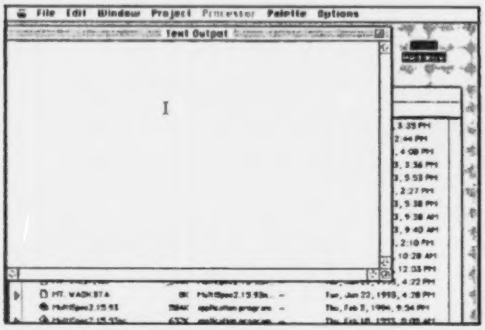
- Turn on you computer.
- To open the hard drive, if it is not open already, double click on the **hard drive** icon.
- Pull down the **File** menu and select **New Folder**. A new untitled folder should appear on the screen. While the words **untitled folder** are highlighted, replace them by typing **MultiSpec Folder**. Press **return**.

If your computer does not have a math coprocessor or if you do not know if it does:

- Insert the disk labeled **MultiSpecxx.xx.xxnc Disk**. (**xx.xx.xx** will be a specific edition of the current MultiSpec software. Any reference to a specific edition, such as **MultiSpec2.15.93**, is **only an example of an edition for purposes of this tutorial and will not reflect the most current edition.)**
- Double click on the **MultiSpecxx.xx.xxnc Disk** icon to open the disk. **MultiSpecxx.xx.xxnc** is the non-math coprocessor version of the MultiSpec program. Your screen should appear similar to the annotated diagram shown in the figure on the next page.
- Copy the **MultiSpecxx.xx.xxnc** to the **MultiSpec Folder** you created on your hard drive. To accomplish this: click on the **MultiSpecxx.xx.xxnc** application program icon and drag it to the **MultiSpec Folder**. You do not need to copy the **PRF Files** if they are on the disk. (**PRF Files** contains tutorial images referred to in the Purdue Research Foundation complete MultiSpec documentation manual. These files are not used in this tutorial.)
- Close the **MultiSpecxx.xx.xxnc Disk window** by clicking on the **close box** in the upper left hand corner of the window.
- **Eject** the **MultiSpecxx.xx.xxnc Disk** from the computer by clicking on the **MultiSpecxx.xx.xxnc Disk** icon on your desktop and dragging it to the **Trash**.
- Open the **MultiSpecxx.xx.xxnc** application program by first double clicking on the **MultiSpec Folder** on your hard drive to open the folder. Then double click on the **MultiSpecxx.xx.xxnc** application program icon to start the program.

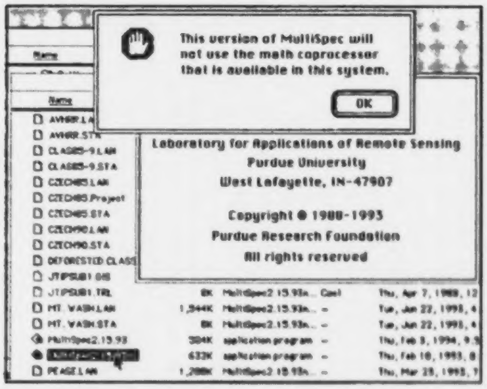
  One of two things should happen:

A. If you do not have a math coprocessor, the program will open immediately and your screen will appear as illustrated below.



You have successfully installed the MultiSpec Program. Proceed to the section entitled QUITTING THE PROGRAM.

B. If you do have a math coprocessor, the message that is illustrated below will appear.



This version of MultiSpec will not use the math coprocessor that is available in this system.

Laboratory for Applications of Remote Sensing
Purdue University
West Lafayette, IN-47907

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If you receive this message, click on **OK**. When the screen pictured in part A above appears, pull down the **File** menu and select **Quit**.

Click on the **MultiSpecxx.xx.xxnc** application program icon in the **MultiSpec folder window** and drag it to the **Trash**.

Close the **MultiSpec folder** by clicking the close box in the upper left hand corner of the window.

You now know you have a math coprocessor. Proceed with the directions that follow.

If you know your computer has a math coprocessor:

- Insert the disk labeled **MultiSpecFatxx.xx.xx Disk**.
- Double click on the **MultiSpecFatxx.xx.xx Disk** icon that appears on the desktop to open the disk. **MultiSpecFatxx.xx.xx** is the math coprocessor version of the MultiSpec program. Your screen should appear similar to the one in the annotated diagram on the preceding Gray Scale insert page.

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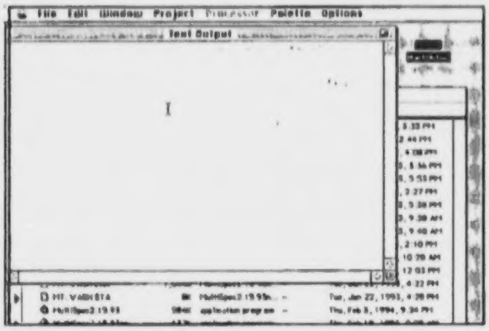
- Copy the **MultiSpecFatxx.xx.xx** program to the **MultiSpec Folder** you created on your hard drive. To accomplish this: click on the **MultiSpecFatxx.xx.xx** application program icon and drag it to the **MultiSpec Folder**. You do not need to copy the **PRF Files** if they are on the disk. (**PRF Files** contains tutorial images referred to in the Purdue Research Foundation complete MultiSpec documentation manual. These files are not used in this tutorial.)
- Close the **MultiSpecFatxx.xx.xx Disk window** by clicking on the **close box** in the upper left hand corner of the window.
- To **eject** the **MultiSpecFatxx.xx.xx Disk**, click on the **MultiSpecFatxx.xx.xx Disk** icon on your desk top and drag it to the **Trash**.
- Open the **MultiSpecFatxx.xx.xx** application program by first double clicking on the **MultiSpec Folder** on your hard drive to open the folder. Then double click on the **MultiSpecFatxx.xx.xx** application program icon to start the program.



- You have successfully installed the MultiSpec Program if your screen looks similar to the one shown on the preceding page.

Quitting the Program

Now that you know how to open the program, we will exit (quit) the program in order to install the images and address memory options.

- Pull down the **File** menu and select **Quit**.

Installing LANDSAT Images

- Insert the disk labeled **Beverly,MA Disk**.
- Double click on the **Beverly,MA Disk** icon to open the disk.
- Click and drag the **BEVERLY,MA.LAN** icon to the **MultiSpec folder** on your hard drive to copy that file to your hard drive.
- Click and drag the **BEVERLY,MA.STA** icon to the **MultiSpec folder** on your hard drive to copy that file to your hard drive.
- Close the **Beverly,MA Disk** window by clicking on the **close box** in the upper left hand corner of the window.

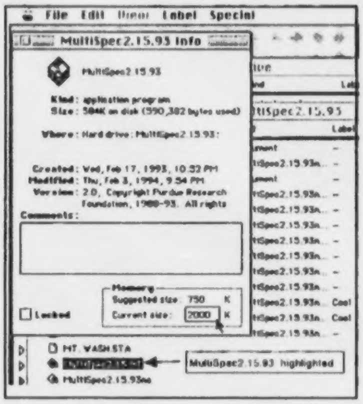
- Click on the **Beverly,MA Disk** icon and drag it to the **Trash** to **eject** the disk.
- It is important that the **.LAN** files and the **.STA** files be placed in the **MultiSpec folder** on the hard drive. The **.STA** files contain statistics for the display of the applicable images.

Memory Options

The MultiSpec programs you received have been preset to use 2 megabytes (2000K) of RAM. This is sufficient for 8 bit color. If you do not have at least 4 megabytes of RAM on your Macintosh computer or you would prefer not to address memory concerns at this time, **you may skip this section**.

If you wish to change the amount of RAM assigned to this program, you may proceed with the following steps.

- Be sure you have quit the MultiSpec program.
- If the **MultiSpec Folder** is not open, open it now by clicking on the arrow to the left of the words MultiSpec Folder on the hard drive. The arrow will point downward and reveal the contents of the folder. Highlight the **MultiSpec application program** on your hard drive by clicking ONCE on the icon identifying the program. DO NOT double-click on the application program icon or you will open the program at this time. You do not want the application program open for this procedure, just selected (highlighted).
- With the **MultiSpec** application program highlighted, pull down the **File** menu and select **Get Info**. You should see the following on your screen.



Kind: application program
Size: 584K on disk (590,382 bytes used)
Where: Hard drive: MultiSpec2.15.93:
Created: Wed, Feb 17, 1993, 10:52 PM
Modified: Thu, Feb 3, 1994, 9:54 PM
Version: 2.0, Copyright Purdue Research Foundation, 1988-93. All rights
Comments:
☐ Locked
Memory
Suggested size: 750 K
Current size: 2000 K

- In the **Memory** box, where the small arrow in the diagram points, edit the **Current size** box to read 4000 K.
- Close the **Get Info** window. You are now ready to run the program.

Investigating a satellite image

Materials needed:

Macintosh computer with **BEVERLY,MA.LAN** image installed

700

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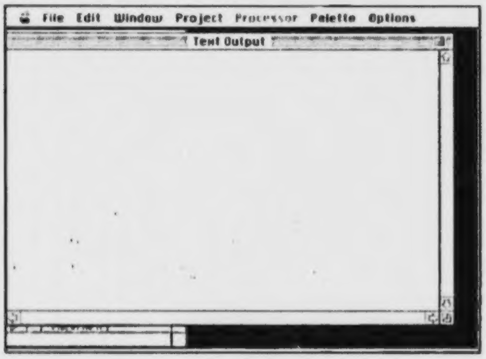
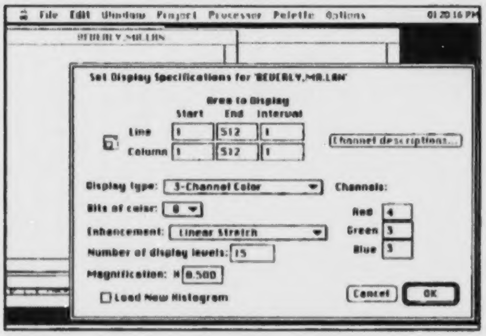
Getting Started:

- After turning on your computer, open the hard drive by double clicking on the hard drive icon.
- Double click on the **MultiSpec folder** to open it.
- Double click on the **MultiSpecFatxx.xx.xx** (or **MultiSpecxx.xx.xxnc**) icon to start the MultiSpec program. The window labeled **Text Output** should appear. Your screen should be similar to the one shown in the diagram below.


File
Edit
Window
Project
Processor
Palette
Options
Text Output

- Pull down the **File** menu and select **Open Image**. Double click on **BEVERLY,MA.LAN** to select that Landsat satellite image.
- You should now have a dialogue box entitled **Set Display Specifications for 'BEVERLY,MA.LAN'** displayed on your screen.


File
Edit
Window
Project
Processor
Palette
Options
01:20:16 PM
BEVERLY,MA.LAN
Channel descriptions...
Cancel
OK

Set Display Specifications for 'BEVERLY,MA.LAN'

	Area to Display Start	End	Interval
Line	1	512	1
Column	1	512	1

Display type: 3-Channel Color

Bits of color: 8

Enhancement: Linear Stretch

Number of display levels: 15

Magnification: x 0.500

☐ Load New Histogram

Channels:

Red 4

Green 3

Blue 3

- Click on the box labeled **Display type** and be sure **3-Channel Color** is selected.
- **Leave 8 bits of color selected!** (If you have assigned more than the standard amount of RAM to this program and you have 24 bits of color available on your computer, you may do the following: Click on the Bits of color box and select **24**.) If you select 24 bit color when you do not have enough memory assigned, you will receive messages telling you "**not enough memory is available**" and your display image will have problems. This message is not referring to the amount of memory in the computer but to memory allocation.

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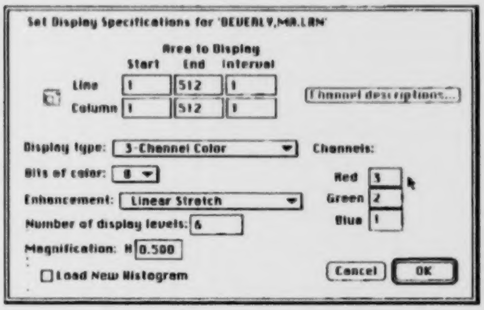
- Under **Channels** set **Red** box to **3** , **Green** box to **2** , **Blue** box to **1** and click **OK** NOTE: BACKSPACING OR DELETING THE OLD NUMBER FIRST IN THIS PROGRAM MAY NOT WORK. To edit the number appearing by each color, click to the left of the number and, without releasing the mouse button, drag the mouse to the right or double-click on the box. This should highlight the number you want to change. When it is highlighted, release the mouse button. The box should stay highlighted. Now type the number you wish to enter in the box. You may use the **tab** key to move between boxes on the screen.



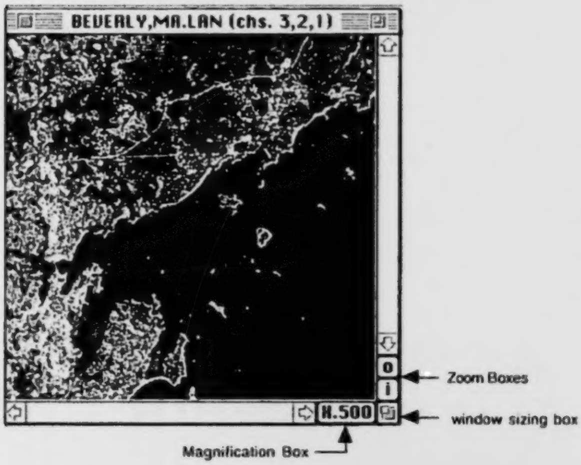
Set Display Specifications for 'BEVERLY,MA.LAN'

	Area to Display		
	Start	End	Interval
Line	1	512	1
Column	1	512	1

Display type: 3-Channel Color
Bits of color: 8
Enhancement: Linear Stretch
Number of display levels: 6
Magnification: X 0.500
☐ Load New Histogram

Channels:
Red 3
Green 2
Blue 1

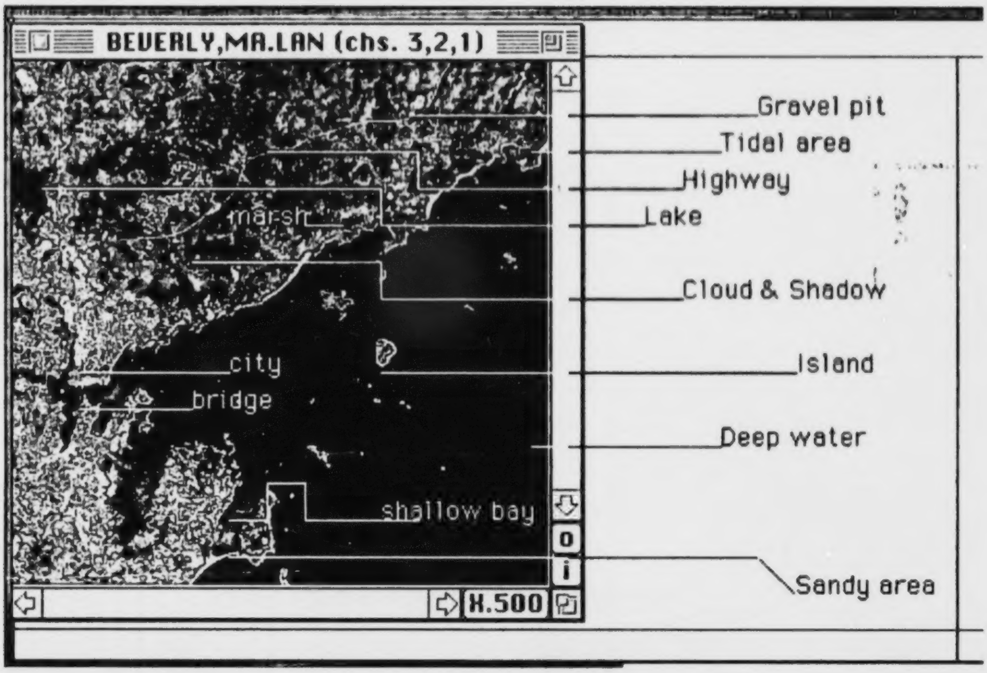
- Click **OK**. The image display should now appear in the upper left of your screen. At **X.500** magnification you can see the entire image at once.



- To enlarge the window, click in the window sizing box in the lower right corner of the image window and drag the box to the right and down. In the lower right hand corner of the image window, just to the left of the window sizing box is the magnification box that shows X.500.

Click on that box. The box should now read X1.0 and the image should enlarge and fill (or almost fill) the viewing window depending on how much you enlarged the image window. You have to scroll up or down to see the whole image when the magnification is X1.0 unless your monitor is 17-inches or larger.

1. Try to identify roads, bridges, lakes, towns, regions with trees, beaches, marshy regions near the shore, shallow ocean waters. What other features do you notice?


BEVERLY,MA.LAN (chs. 3,2,1)
Gravel pit
Tidal area
Highway
marsh
Lake
Cloud & Shadow
city
Island
bridge
Deep water
shallow bay
o
i
Sandy area
X.500

2. Zooming:

Notice that just above the window sizing box in the lower right hand corner there are two small boxes labeled **(i)** and **(o)**. These are zoom boxes allowing you to zoom in and out from the current image scale. Notice the magnification box **X1.0** in the lower right hand corner of the viewing window. Click the **i** once. Now click on **i** many, many times. You should eventually see the image appear as a mosaic of squares (pixels) on the screen. Observe the numbers appearing in the magnification box as you click on **i** or **o**. As you zoom in and out, this box gives zoom factors. **X1.0** means full size image. Before proceeding to #3, click on the magnification box. The image should now be full size and the magnification box should read **X1.0**.

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Questions:

a. What do you notice about the length of objects when you zoom in? when you zoom out?

Objects increase/decrease in length proportionately with the zoom factor.

b. What information is gained when you zoom in or out? What information is lost?

When you zoom in, you can focus on a smaller region. Eventually the image becomes a mosaic of pixels. When you zoom out, you can see a larger region at once.

Click on the **magnification** box to return the display image to full size. The magnification box should read **X1.0**.

3. Zoom Box:

You also can zoom in on a specific region by boxing the region and zooming. Place the mouse pointer at the upper left corner of the area you wish to box. then click and hold the mouse button while moving the mouse to the right and down. When you have boxed off the desired area, release the mouse button; notice that the region you selected is delineated by dashed lines. Click on **zoom in (i)**. You can continue to zoom in on the selected region by continuing to click on **(i)**. What do you observe? If the zoom box is not square, do the image proportions appear to change? Give reasons for your answer.

The proportions of a figure do not change. Lengths all change proportionately. Shape stays the same, size changes.

To zoom in or out by tenths, hold down the **option** key while clicking on **zoom in (i)** or **zoom out (o)**.

Return to the full image by clicking on the magnification box so it reads **X1.0**.

4. Panning:

In order to move (pan) around the image, first hold the **option** key down and a hand icon will appear. Clicking and holding the mouse button down while moving the mouse will cause the image to move in conjunction with the mouse. As with all Macintosh applications, you can also use the scroll bars to pan.

(To exit the program at any time, under the **File** menu select **quit**. Close all remaining windows before selecting **Shut Down** under the **Special** menu.)

Investigating color in a satellite image

Image Display:

Under the **Processor** menu select **Display Image**.

Please read the following information about color and Landsat satellite images. The colors red, green, and blue refer to the computer monitor color guns. (They apply red, green and blue light to each pixel in specific intensities.) The **channels** (often called **bands**) refer to bands of reflected light sensed by the satellite from the objects in the image. Band 1 is reflected blue light, band 2 is reflected green light and band 3 is reflected red light. Red, green, and blue are the primary colors of visible energy. Different hues (shades) of color are obtained on the screen when color guns apply different intensities of red, green, and blue light to the same pixel. For example, equal intensities of red and green light produce yellow; equal intensities of blue and green light produce cyan; and equal intensities of blue and red light produce magenta. Bands 4 and 5 receive reflected near infrared and mid infrared energy, respectively.

We will use the following red, green, and blue (RGB) channel settings in order to get a feel for different channel (band) combinations.

True color images - This band combination presents an image as it would appear to the human eye, looking back from space.

Red	3 (the visible red band)
Green	2 (the visible green band)
Blue	1 (the visible blue band)

Other band combinations result in images that do not appear as they would to the human eye. These images are called **false color images**. Enter the following band combinations and observe the results.

A. The band combination below mimics infrared aerial photographs. Plant material, which reflects a great deal of infrared energy, will stand out as bright red with this band combination. This is useful to people studying forests.

Red	4 (the near Infrared band)
Green	3 (the visible red band)
Blue	2 (the visible green band)

B. This band combination is especially good for separating trees and grassland. The conifer or evergreen trees appear as intense dark green, deciduous trees appear as medium green, and grassland appears as light green or yellowish green.

Red	5 (the mid Infrared band)
Green	4 (the near Infrared band)
Blue	2 (the visible green band)

Use the computer image of **BEVERLY,MA.LAN** for the following activity.

Locate the features in the chart on the next page using each of the Red, Green, Blue (RGB) channel settings listed. Record the color of each feature under each channel (band) combination. RGB 321 means assign Channel 3 to the red color gun, Channel 2 to the green color gun and Channel 1 to the blue color gun. TO CHANGE COLOR GUN ASSIGNMENTS PULL DOWN THE **PROCESSOR** MENU AND SELECT **DISPLAY IMAGE**.

Trouble shooting hints:

If, by mistake, you pull down the File menu and select open image, you will have to correct ALL settings, instead of just the color assignments. To do this, go back to the GETTING STARTED directions to be sure you do this correctly.

If you end up with a very tiny image it means you selected a small piece of the image by mistake and asked to have it displayed. Under the **Processor** menu select **Display Image**. Click on the small box in the upper left hand corner to the left of the words: **Line** and **Column**. This will return the image to the full 512 by 512 pixel display.

Complete the chart, recording the color of each feature under each channel (band) combination.

	RGB	**RGB**	**RGB**
	321	432	542
- Beaches			
- Highways			
- Regions with trees			
- Ocean			
- Cities or towns			

Try other channel (or band) combinations and write your observations.

Reference Page

MultiSpec Bands and Their Uses

Band	Principal applications
1 Blue visible light	Useful for mapping water near coasts, mapping forest types, differentiating between soil and plants, and identifying human made objects such as roads and buildings (cultural features).
2 Green visible light	Useful for differentiating between types of plants, determining the health of plants, and identifying cultural features.
3 Red visible light	Useful in differentiating between plant species differentiation and identifying cultural features.
4 Near-Infrared energy	Useful for determining plant types and plant health and for seeing the boundaries bodies of water.
5 Mid-infrared energy	Useful for distinguishing snow from clouds and determining vegetation and soil moisture content.
6 Thermal- infrared energy	(Not included on Landsat Unit disks) Useful in determining relative temperature and determining the amount of soil moisture.
7 Mid-Infrared energy (longer wavelength than band 5)	(Not included on Landsat Unit disks) Useful for differentiating between mineral and rock types and telling how much moisture plants are retaining.

Reference: Lillesand, Thomas M. & Kiefer, Ralph W. (1987). *Remote Sensing and Image Interpretation*. 2nd Edition. New York: John Wiley and Sons. P. 567.

Color My World

Preparation Reading:

Previously you changed the colors on the computer image. When you change the colors, objects may be distinguishable as different colors or become indistinguishable when they blend with the color of other objects around them. The five channels on the images portrayed by the computer imaging MultiSpec program contain data from one of five different bands of the electromagnetic spectrum. For each of the five bands, Landsat 5 senses reflected light or energy and assigns a reflectance number to represent the brightness level.

Three of these bands are in the visible range: channel 1 is blue reflected light, channel 2 is green reflected light, and channel 3 is red reflected light. Reflected red, green, and blue light are all useful for distinguishing between human made objects, such as roads and buildings, and natural features, such as rivers, lakes, and mountains.

The other two channels, channels 4 and 5, are in the infrared range, invisible to the human eye. Reflected infrared energy is useful if you wish to determine plant types, determine plant health, distinguish between snow and clouds, or identify mineral and rock types. When you selected different numbers for 3-channel color for **BEVERLY,MA.LAN**, you asked the computer to display three bands of the electromagnetic spectrum.

You can display an image in 1-channel color. Your image will then display brightness levels of only one band of the electromagnetic spectrum, such as red visible light or near infrared energy.

In this lesson you should try to become comfortable with categories of objects based on their reflectance in the different bands of the electromagnetic spectrum. This will help you better understand the Landsat 5 imagery.

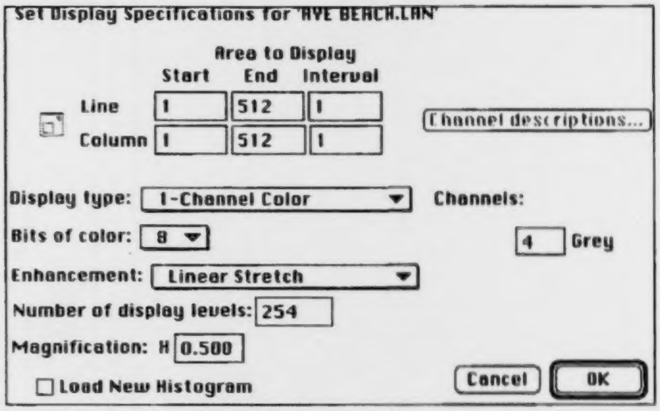
Materials you will need:

Two Macintosh computers with MultiSpec and the **BEVERLY,MA.LAN** image on each.

Each group will need to team with another group and use both computers. If you are fortunate and have one computer available for each student or pair of students, you may want to do this activity in a larger group using the three computers. This activity can also be accomplished on one computer if you have enough memory to open multiple copies of the **BEVERLY,MA.LAN** image.

We will explore the connection between electromagnetic energy and the channels which can be selected in the **Display Image** option under **Processor** in the MultiSpec menu. You will probably want to keep handy the "Reference Page: MultiSpec Bands and Their Uses".

- If you are restarting your computer, follow the first four steps in GETTING STARTED to get to the dialogue box entitled Set Display Specifications for BEVERLY,MA.LAN.
- Click on the box labeled Display type and select 1-channel color.
- Click on the box labeled Bits of color and select 8 or 24 if you have the required memory.



Set Display Specifications for 'AYE BEACH.LAN'

Area to Display

	Start	End	Interval
Line	1	512	1
Column	1	512	1

Display type: 1-Channel Color

Bits of color: 8

Enhancement: Linear Stretch

Number of display levels: 254

Magnification: X 0.500

Channels: 4 Grey

☐ Load New Histogram

- Now the directions change for the two computers:

- On one computer, type in 4 for the channel (next to the word "Grey"). (Remember to highlight the number to be changed and then type the new number. Backspacing or deleting the old number first does not always work in this program.) Press return or click on OK.

  The gray scale image you see represents the reflectance levels of one band of electromagnetic energy. What band is that?

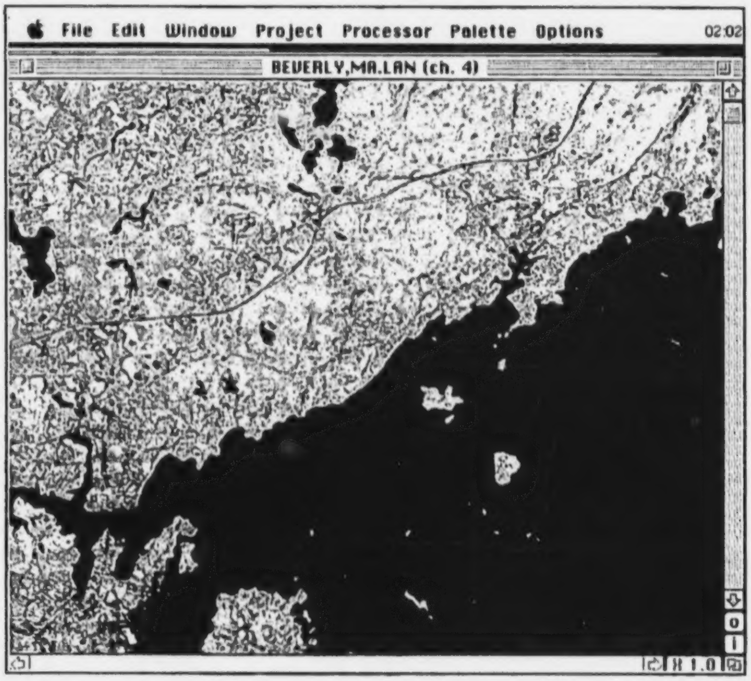
  Is it a visible band?

- On the other computer, type in 3. Press return or click on OK.

  What band of electromagnetic energy is transmitted through channel 3? Is it a visible band?

- If you have a third computer, select another visible band to view.

- After the image is displayed, enlarge the viewing window to approximately twice the size. Click on X.500 in the lower right hand corner of the viewing window to enlarge the image. The box should change to X1.0.



- Scroll to make sure the image display on each computer shows the same region of the image.
- Keep these two images on the screens of the respective computers, making sure everyone can see both screens. The images will be in shades of gray.
- You will need to change the channels on the computers you are using to answer the questions below. To do that, select the Display Image option under Processor in the MultiSpec menu and just change the channel number.

Please read:

If an object has a high reflectance level for a particular band, it appears very bright (nearly white). If it has a very low reflectance, it absorbs most of that band and appears very dark (nearly black). For example if an object reflects more blue light than red light, it will appear lighter in the image for which the selected channel is 1 for blue light than in the image for which the selected channel is 3 for red light.

Answer the following as completely as you can:

1. You should be able to distinguish trees, the railroad bridge between Beverly and Salem, and shallow bays more easily in one image display, but not in the other. Roads are bright in one image and dark in the other. Explain these observations with reference to the red and near-infrared bands of the electromagnetic spectrum.

Trees absorb red light and appear dark in the red band and can be distinguished from beaches and grasslands. In the near-infrared band the trees appear very bright because they reflect near-infrared energy. They are not easily distinguishable from the grassland.

The shallow water east of the Beverly-Salem bridge reflects a small level of visible red light and appears lighter than the deeper ocean. All water areas absorb near-infrared energy and mid-infrared energy.

The railroad bridge reflects red light and is visible in the red band. It absorbs near-infrared energy and is not easily distinguishable in the infrared band.

Highways reflect red visible light and absorb near infrared energy.

2. List other objects that have either high reflectance of visible red light and low reflectance of near infrared energy or high infrared and low visible red.

   Buildings, often called cultural features because they are human made, reflect visible red light but absorb near infrared energy.

Note: To answer the following questions you will have to change the bands on the computers and make comparisons.

3. Cultural features are human-made features such as roads, buildings, and bridges. What do you notice about their reflectance of visible light and infrared energy? On the computer that displays visible red light, change the channel to visible green (band 2) and then visible blue (band 1) to answer this question.

   Cultural features have high reflectance of all visible light and low reflectance of near-infrared energy.

4. What do you observe about the relative reflectance of a) red, b) blue, and c) green light; and d) near-infrared energy by the ocean? For an extra project, you may want to do some library research to determine why bodies of water appear blue when you actually look at them.

   Bodies of water absorb almost all energy, but blue visible light will reflect more than other bands.

5. What do you observe about the relative reflectance of a) red, b) blue, and c) green light; and d) near-infrared energy by trees?

   Trees reflect low levels of red and blue visible light and slightly higher levels of visible green light. They reflect high levels of near and mid infrared energy.

6. What do you observe about the relative reflectance of a) red, b) blue, and c) green light; and d) near-infrared energy by "cultural features"?

   Cultural features reflect all visible light and low levels of near-infrared energy.

7. There is a cloud over Beverly and several other small clouds in the image. Try various bands to make observations about the reflectance of clouds?

   Clouds reflect all visible light and all infrared energy. This is why cloud free images are important to distinguish surface features of the earth. Clouds "hide" the earth. Radar does penetrate clouds. Landsat 6 that was not successfully launched had a radar sensor.

8. Shadows of clouds and lakes appear dark in the image. Try various bands to develop ways to distinguish cloud shadows from lakes.

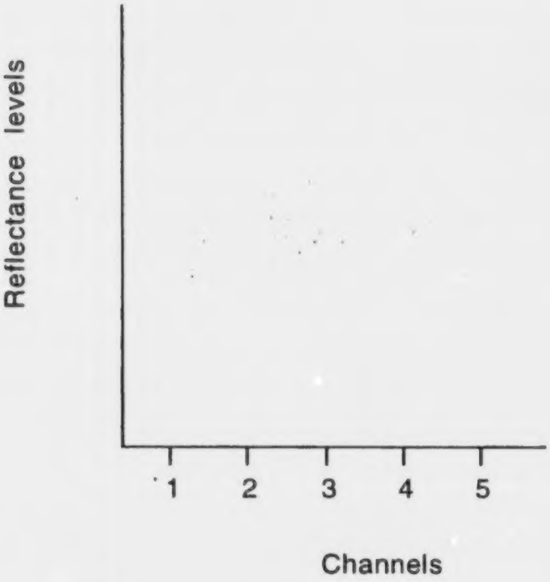
   Lakes reflect low levels of visible light and essentially no infrared energy. Shadows are "transparent" and reflect whatever is beneath them. This means that if they are over trees, the region in the shadow will reflect high levels of infrared energy.

9. Write a question about color and images and either answer it yourself or have a neighboring group try to answer it. Write the question and answer here.

Answers will vary.

10. The designer of the chart below did not finish her work.

    a. Insert the scale on the "reflectance levels" axis.
    b. Insert the words that go with the numbers on the "channel" axis.



11. Suppose you had selected a pixel that contained only trees. On the chart in #10, try to predict a channel reflectance value for each band. Use your answer to question 5 for help in answering this question.

Graphing

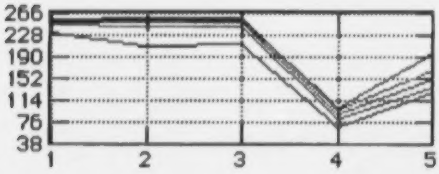
Preparation Reading:

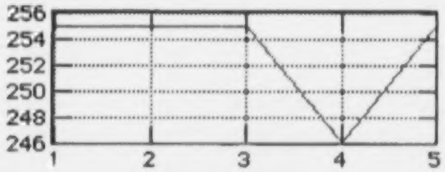
The histograms you will be studying are of the reflectance values at each of the 5 wavelengths the satellite measures. On the horizontal scale the numbers 1 through 5 refer respectively to the blue, green, red, near-infrared, and mid-infrared wavelengths. The vertical scale ranges from 0 (no reflectance) to 255 (maximum reflectance). Sometimes the vertical scale will go beyond 255, but the values plotted never exceed 255. Note that the graph really only has meaning when read at the horizontal positions of 1, 2, 3, 4, or 5. The line segments which connect the points don't represent reflectance values of other wavelengths. They simply make the graph easier to read.

The red line is the average of the reflectance of all the pixels in the selected area. The green lines mark off all reflectance within 1 standard deviation of the average, and the blue lines mark the minimum and maximum values. A formal definition of standard deviation is not developed. You are simply instructed that the green lines contain about 66% of the reflectance in the selected area.

Mathematically the primary emphasis should be on the interpretation of graphs. You will be viewing graphs that are automatically scaled to fill the window. While convenient, this feature can be confusing as the vertical scale can change dramatically from one region to the next. So although two graphs may look the same their vertical scales could be vastly different. This phenomenon highlights the difference between two graphs having the same relative shape but different absolute shapes.

For example, consider the two graphs on the following page, while the relative shapes are about the same, the absolute shapes are very different. The histogram on the left has a dip on band 4 as does the histogram on the right, however, the dip on the histogram on the right is very small compared to the one on the left! Note that the dip on the right actually looks larger than the dip on the left. It is when we look carefully at the vertical scales, however, that we discover that the dip on the left is a change of almost 200 intensity values while the dip on the right is of only 9 intensity values! The dips are in the same relative position on both graphs but of very different absolute sizes.





How can we classify and discriminate between regions on an image using histograms?

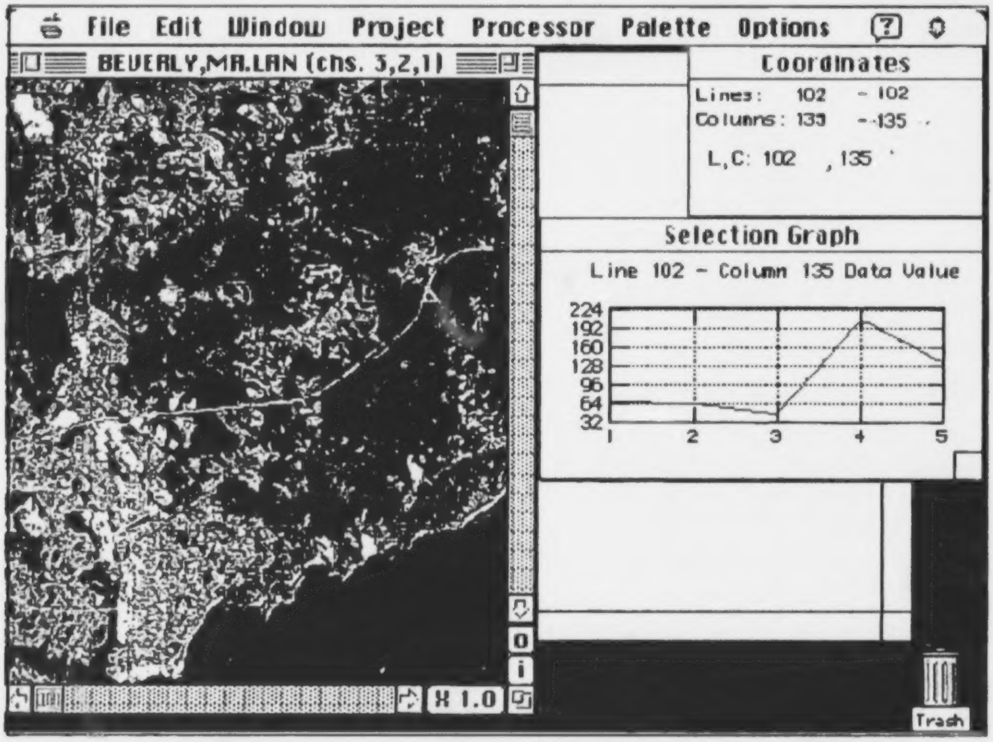
By now you should understand that the images we have been studying are based on numbers that represent the intensity of reflected light at five different wavelengths. Stretching the image and assigning various colors to different wavelengths helped us discriminate between similar looking regions that were in fact different. But some regions still may appear similar on the computer screen even though they represent different objects on earth. In this lesson we learn how to use another tool of the MultiSpec program to help us classify regions, and discriminate between different regions.

Which of These Things Doesn't Belong?

At the computer, start the MultiSpec program and open an image of Beverly, MA. Assign the colors red, green, and blue to bands 3,2,1 to generate a true color image.

Now choose **Show Selection Coordinates** from the **Options** menu. Now select **New Selection Graph** from the **Options** menu. Click anywhere on the image window to highlight it, and click again on any one pixel of the image.

By re-sizing the windows (lower right box of a window) and moving the windows around the desktop (drag the window by its title bar) arrange the windows so that they appear similar to the figure on the next page.



Coordinates

Lines: 102 - 102

Columns: 133 - 135

L,C: 102 , 135

Selection Graph

Line 102 - Column 135 Data Value

Coordinates Window

In the upper right hand corner of the figure above is the Coordinates window. This window allows you to know exactly what part of the image you are selecting when you click on the image window. The coordinates of the cursor are given as an ordered pair with the line number given first and the column number given second. In this figure the pixel selected is the one at (102, 135). Depending on the magnification factor you are using you may have to use the scroll bars on the image window to find a particular pixel.

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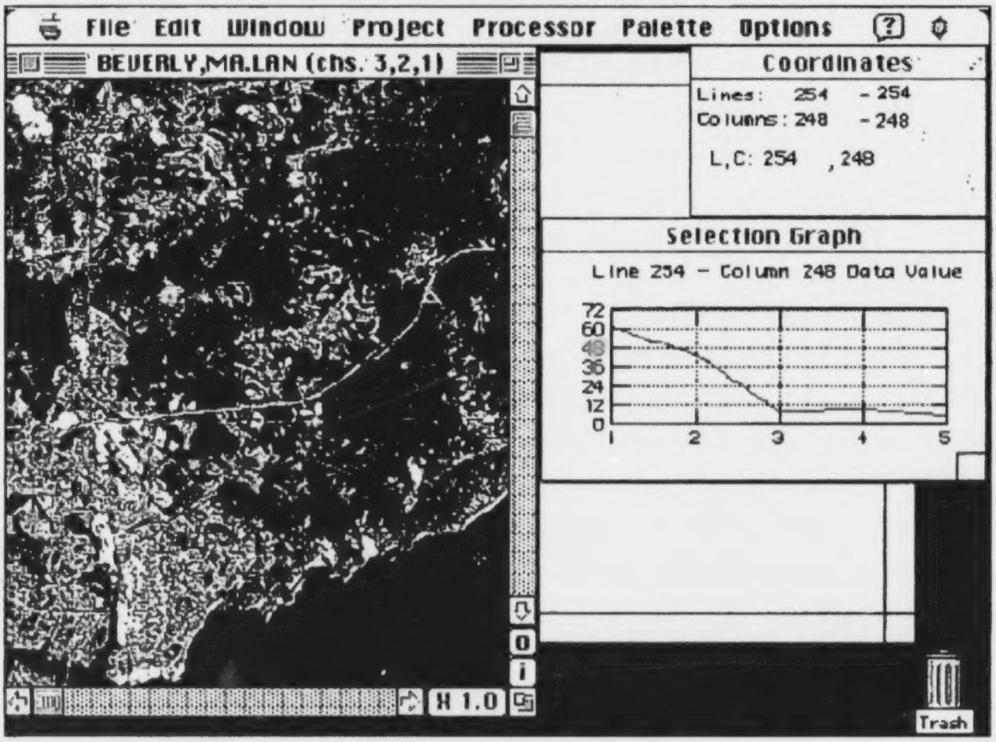
Selection Graph

Below the Coordinates Window is the Selection Graph window. This is the window you should learn to use during this computer session. It is a graph of the reflectance values of the pixel (or pixels) you have selected. In the above figure the graph is for the pixel located at (102,135).

This graph provides valuable analytical information. The bottom axis has labels 1, 2, 3, 4, and 5 that correspond to the blue, green, red, near-infrared, and mid-infrared wavelengths that Landsat monitors. The vertical scale corresponds to the numerical value of the reflectance. This scale can range from 0 to 255. A 0 would represent very little reflected light and a 255 would represent a lot of reflected light. Remember that these values may be the result of stretching the data. The pixel we have selected is brightest in bands 4, and darkest in band 3. This means that the object at this location on the earth is reflecting more near-infrared light than light of the other wavelengths.

Now click anywhere on the image window to activate it. Then click on the pixel with coordinates (L,C) = (254,248) that is down on the ocean. At this point we find reflectances of about 60, 44, 10, 11, and 6. See figure below for an idea of what your screen should resemble.



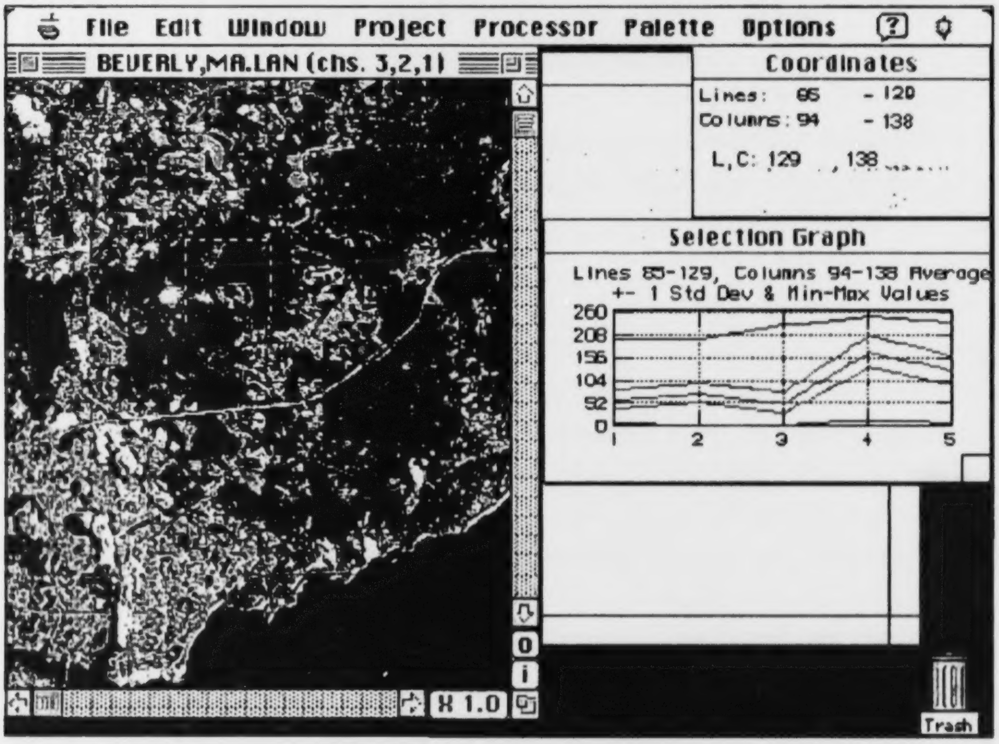
Lines: 254 - 254
Columns: 248 - 248
L,C: 254 , 248

Line 254 - Column 248 Data Value

Note that the reflectances are lower at every one of the five bands than for the previous pixel at (102,135).

This difference makes sense since we expect the ocean to be darker than ground. If you have ever flown over ocean and trees you will have noticed how the ocean appears almost black while the trees do appear brighter. The fact that water absorbs most all of the energy that falls on it can help us determine if an unknown dark region is water or not.

Now click and drag in the image window to select a rectangle of many pixels. We selected a rectangle with its upper left corner at pixel (L,C) = (85,94) and its lower right corner at (L,C) = (129,138). Try to select these same pixels for the upper left and lower right corners of your rectangle. The result should resemble the figure.


File
Edit
Window
Project
Processor
Palette
Options
BEVERLY,MA.LAN (chs. 3,2,1)
X 1.0
Coordinates
Selection Graph
Lines 85-129, Columns 94-138 Average
+- 1 Std Dev & Min-Max Values
260
208
156
104
52
0
1
2
3
4
5
Trash

Lines: 85 - 120
Columns: 94 - 138
L,C: 129 , 138

Note that now the selection graph contains 5 lines. The red line is the average of the reflectance of all the pixels in the rectangle we selected. The green lines mark off a range that contains the middle 66% of the reflectance values. The blue lines indicate where the minimum and maximum values are for the reflectance of all the pixels we selected.

For example look at the reflectance on band 4. Of all the pixels selected in the rectangle the lowest reflectance is about 10, the highest reflectance value is around 255, 66% of the reflectance is between 130 and 208, and the average reflectance is about 160.

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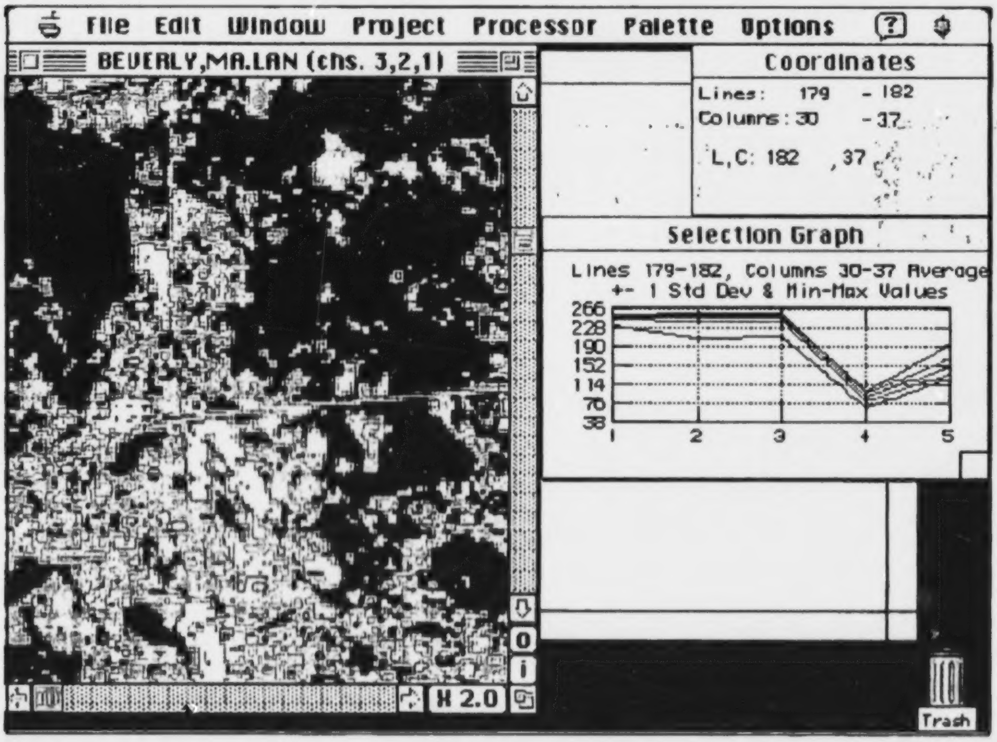
Using the Histogram Window to Discriminate Between Different Regions

We can use the histogram window to help us identify similar and different regions. What we will do is find an area of interest and save its histogram to compare with a second histogram of another area of interest.

Go to a magnification of **X2.0**. Click and drag the mouse to select a rectangle with upper left corner (L,C) = (179,30) and lower right corner (L,C) = (182,37). Your screen should resemble the figure below.


File
Edit
Window
Project
Processor
Palette
Options
BEVERLY,MA.LAN (chs. 3,2,1)
Coordinates
Selection Graph
266
228
190
152
114
70
38
1
2
3
4
5
X 2.0
Trash

Lines: 179 - 182
Columns: 30 - 37
L,C: 182 , 37

Lines 179-182, Columns 30-37 Average
+- 1 Std Dev & Min-Max Values

Now choose **Keep Selection Graph** from the **Options** Menu. A new selection graph appears and the old selection graph will remain fixed even if you select a new set of pixels. Position the second selection graph below the first graph so that your display resembles the figure below.

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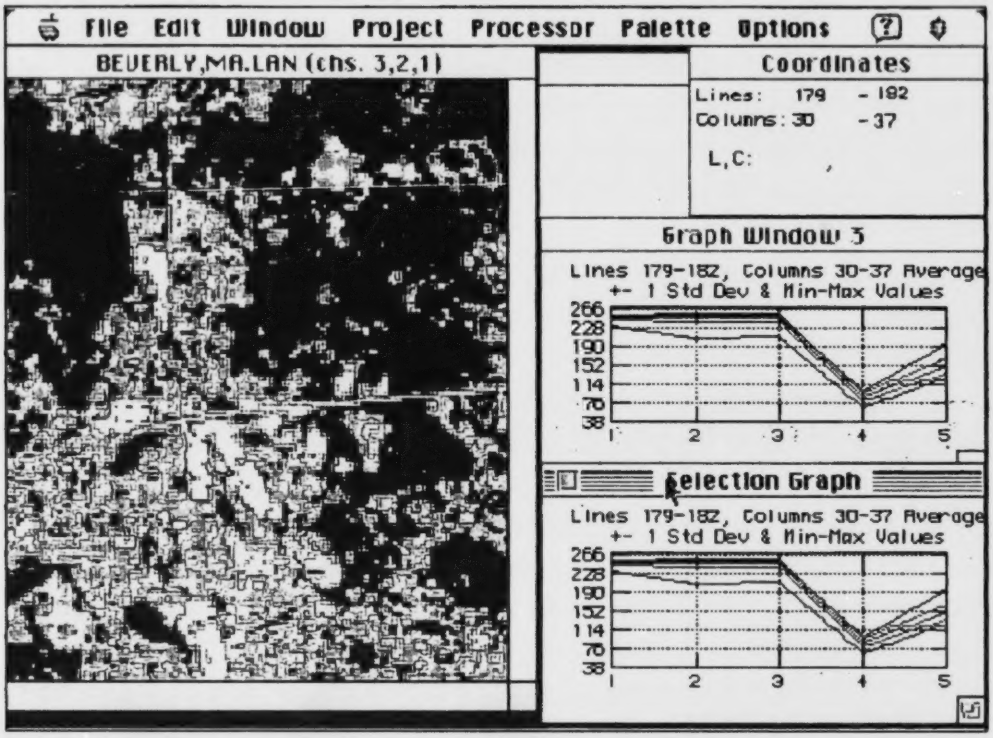
File Edit Window Project Processor Palette Options
BEVERLY,MA.LAN (chs. 3,2,1)
Coordinates
Graph Window 3
Lines 179-182, Columns 30-37 Average
+- 1 Std Dev & Min-Max Values
266
228
190
152
114
70
38
1
2
3
4
5
Selection Graph
Lines 179-182, Columns 30-37 Average
+- 1 Std Dev & Min-Max Values
266
228
190
152
114
70
38
1
2
3
4
5

Lines: 179 - 182
Columns: 30 - 37
L,C: ,

After your screen looks similar to the one in the figure above, click in the image window to activate it, and then click on an image pixel. Note that the top graph stays the same and only the bottom graph changes. Displaying both graphs allows us to compare the histogram of a new region with the saved histogram of the white region visible in the image. This white region is near a road and in the city limits of Beverly. It is very likely that this bright area is caused by light reflecting off large buildings with metal or concrete roofs.

Select just the one pixel at (L,C) = (210,216). This is a pixel in another white region. It is well outside the town of Beverly. Could this white area also be buildings? Let's compare this region's histogram with the first histogram and try to decide if the objects are the same or different. After selecting the pixel at (L,C) = (210,216) your screen should resemble the figure that follows.

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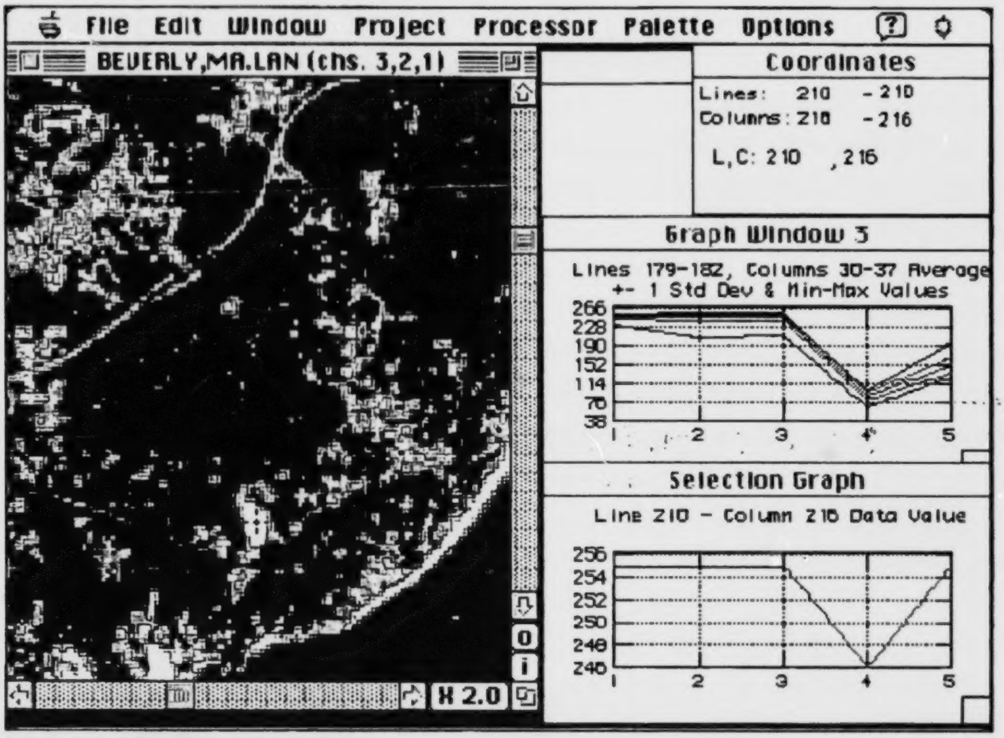
File
Edit
Window
Project
Processor
Palette
Options
BEVERLY,MA.LAN (chs. 3,2,1)
X 2.0
Coordinates
Graph Window 3
Lines 179-182, Columns 30-37 Average
+- 1 Std Dev & Min-Max Values
266
228
190
152
114
76
38
1
2
3
4
5
Selection Graph
Line 210 - Column 216 Data Value
256
254
252
250
248
246
1
2
3
4
5

Lines: 210 - 210
Columns: 216 - 216
L,C: 210 , 216

Absolute and Relative Differences

In the figure above the top graph is of the bright object in the city of Beverly and the graph on the bottom is the histogram of the bright image located where the cross-hair cursor is located at pixel (210,216). Are these bright white regions the same? Their graphs look very similar. Both graphs have a "dip" on band 4.

If we were in a hurry we might conclude from the graphs that these objects are the same. If it was really important to know what was at these locations we of course would do some ground truthing. Sometimes though, ground truthing might be expensive or impractical. In these cases a closer examination of the graphs will have to be our only clue to the identity of the objects.

Look more closely at the two graphs. In particular notice the vertical scales. The MultiSpec program automatically chooses the minimum and maximum values for the vertical reflectance scale. The result is that we may be looking at a very small portion of the entire scale. The advantage is that we see only the portion of the scale that is relevant for the region we have selected. The disadvantage is that comparing two graphs with different scales can be confusing.

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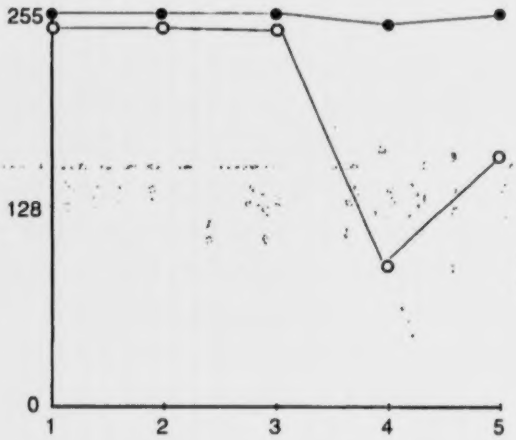
Notice that the top graph drops from the upper 200's on bands 1-3 down to about 90 on band 4. The bottom graph drops from 255 on bands 1-3 to 246 on band 4. This drop is very slight in absolute terms since it is only a difference of 9 reflectance levels. The drop on the other graph is much greater in absolute terms. On the top graph the drop is about 150 reflectance levels! When the differences are viewed absolutely the two graphs are very different.

The reason the graphs initially appeared the same was because we reacted to the similar relative shape of the two graphs. Both graphs do have "dips" at band 4. To make the difference between the graphs more apparent we can plot the two graphs on axes with the same scale as in the figure below.



The object with the large drop in reflectance on band 4 is reflecting very little infrared energy. The histogram of the other object indicates that it is reflecting a lot of energy at all wavelengths measured by Landsat.

The moral of the story is to be sure whether or not the similarity you notice between two graphs is a relative or an absolute similarity (or difference).

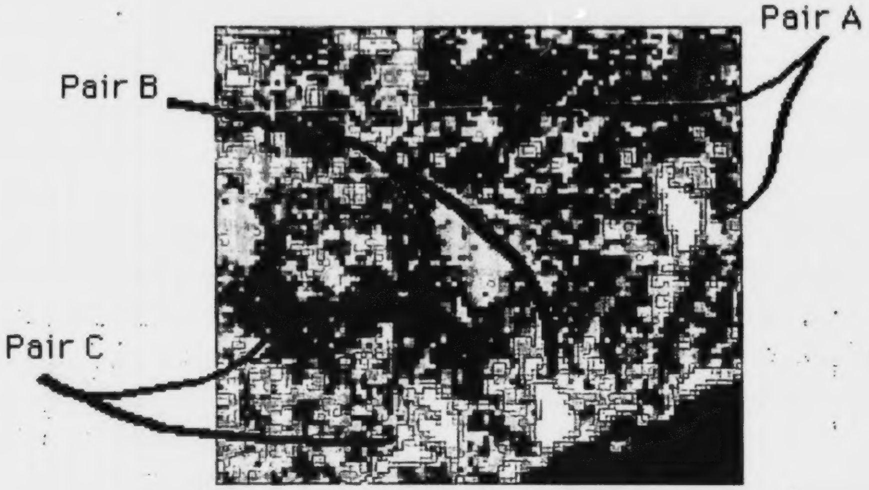
Another Discrimination Exercise

The bright objects to the left of the screen (downtown Beverly) are most likely buildings. We now have evidence (the histograms) that suggest that the bright areas at the right of the screen are not buildings. We have discriminated between two similar appearing but different objects.

But what is that bright feature to the right of the screen?

Use a magnification of **X2.0** and place the unknown bright area near the center of the image window. Notice the three pairs of dark and light regions. The alignment of the three pairs is identical. The dark region is always the same distance away towards the upper left corner of the screen relative to the bright regions. If it hasn't occurred to you already, might these pairs of objects be clouds and their shadows?

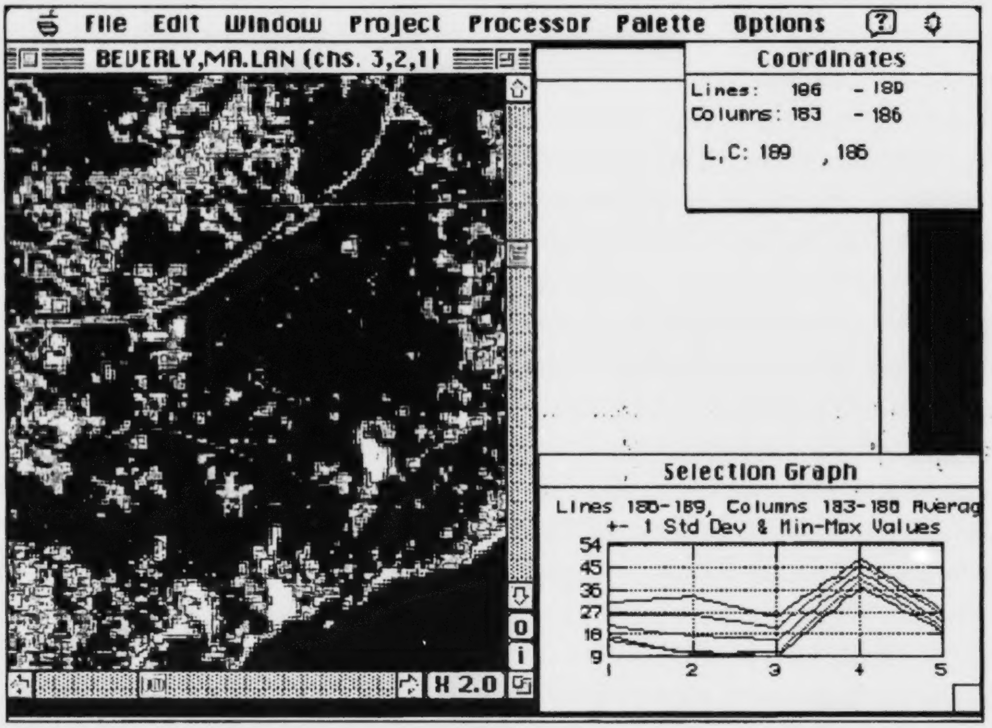
The very similar shapes strongly suggest that we are looking at clouds and their shadows. Note especially how closely the dark object in pair A corresponds to the light object in pair A in the figure below. These must be clouds and their shadows!



But let's be skeptical. What else could these dark regions be? Perhaps they are lakes! Let's get a histogram of one of these dark regions and save it. Then we'll get a new histogram of a known lake for comparison purposes. Here are the steps we can follow to prepare for a new discrimination exercise.

Click in the top graph window to activate it. Now click in the close box (upper left hand corner of window) to close this old histogram.

Click in the image window to activate it. Now select a rectangle of pixels from (L,C) = (186,183) through (L,C) = 189,186). This region corresponds to the dark region that may be a cloud shadow or a lake. You may wish to use a magnification of **X2.0** (or **X1.0**). Your screen should resemble the figure below.


File
Edit
Window
Project
Processor
Palette
Options
BEVERLY,MA.LAN (cns. 3,2,1)
X 2.0
Coordinates
Selection Graph
54
45
36
27
18
9
1
2
3
4
5

Lines: 186 - 189
Columns: 183 - 186
L,C: 189 , 186

Lines 186-189, Columns 183-186 Averag
+- 1 Std Dev & Min-Max Values

When your screen resembles the figure above, move the selection graph from the bottom position to the top position (where the old graph used to be). Next choose **Keep Selection Graph** from the **Options** Menu. Now the top graph will remain constant always displaying the histogram of the possible cloud shadow. Re-size and position the new selection graph window below the top one.

Now let's go find a lake. Click on the image window to activate it. Then scroll up the image window and select the rectangle of pixels from (L,C) = (52,237) through (L,C) = (56,243). This region is definitely a lake as verified by ground truthing. The histogram of this lake region should appear in the bottom graph window. After selecting the known lake region your screen should resemble the figure below.

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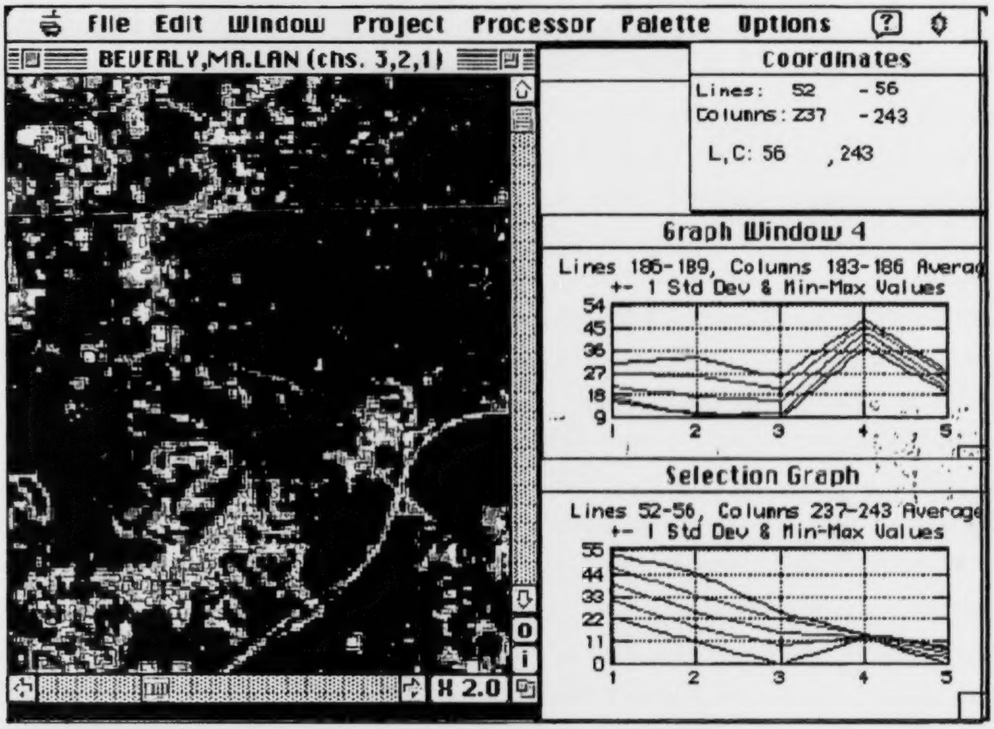
File Edit Window Project Processor Palette Options
BEVERLY,MA.LAN (chs. 3,2,1)
X 2.0
Coordinates
Graph Window 4
Lines 186-189, Columns 183-186 Averag
+- 1 Std Dev & Min-Max Values
54
45
36
27
18
9
1
2
3
4
5
Selection Graph
Lines 52-56, Columns 237-243 Average
+- 1 Std Dev & Min-Max Values
55
44
33
22
11
0
1
2
3
4
5

Lines: 52 - 56
Columns: 237 - 243
L,C: 56 ,243

Note that the vertical scales on these two graphs are almost identical. We can compare these graphs directly and not worry about making mistakes due to relative similarities that are in fact different in absolute terms.

The histogram at the top is of the suspected shadow, and the histogram at the bottom is of the known lake. Are they the same? No. The lake is absorbing much more near-infrared energy (band 4) than is the shadow. The difference in reflectance on band 4 is about a factor of four (11 for the lake compared with 44 for the shadow). This difference makes sense as we would expect the trees in the shadow to reflect more infrared energy than a lake which is an excellent absorber of infrared energy.

Our exploration has come to an end. We have used histograms to identify clouds and their shadows. Now it's your turn to put histograms to use in helping you discover some interesting features of the Beverly image.

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What's That?!

Using the reflectance histogram tool, explore the Beverly, MA image and see if you can find other examples of regions on the screen image that appear the same to your eyes but have very different histograms. You can display up to 12 histograms on the screen at one time for comparison of features.

Some possible explorations include:

Distinguishing beaches and shore, from very shallow water.

Differences between pavement on roads or parking lots and buildings.

Exploring similarly colored areas of vegetation that may have different histograms.

Examining in detail the transition from land to ocean. For example look at the histogram for one pixel at a time beginning with (138,397) and moving east through pixels (138,398), (138,399), (138,400), ..., (138,412).

If you find something interesting write a paragraph that provides a guide to exploring the interesting feature you have found. The guide should be complete enough that someone else can reproduce your explorations. Also include in the paragraph your analysis of the objects you are examining. Support any conclusions you make with arguments based on the histograms of the relevant objects. You can also copy histograms to the clipboard and paste them into another application, such as a word processor, to form a library of representative histograms of specific features. You can then investigate an unknown image and identify features by finding similar histograms to those in the library.

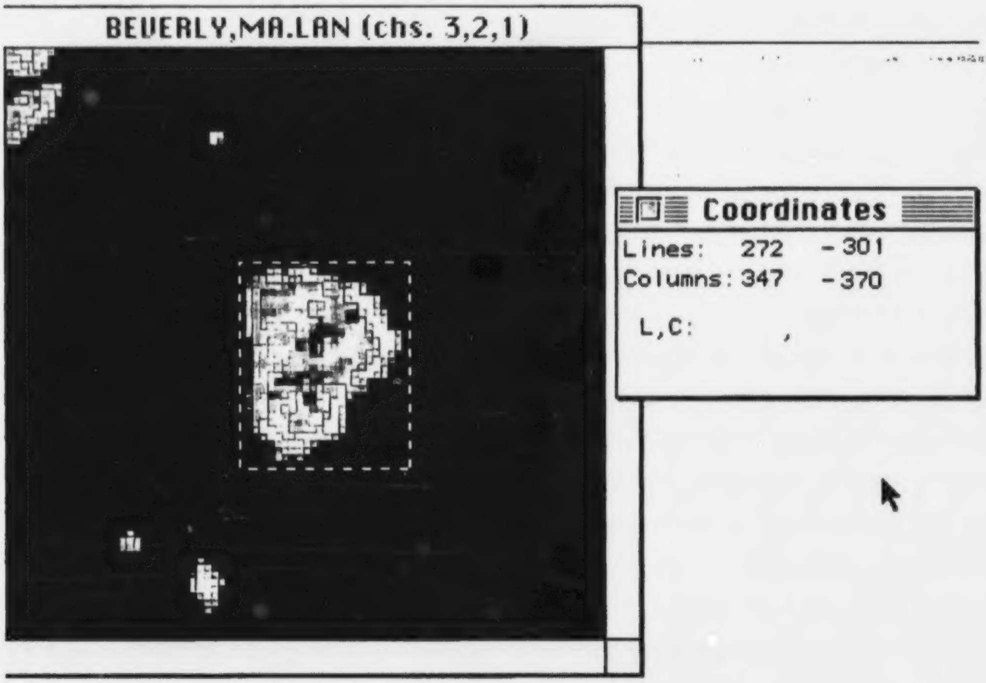
Finding the area of irregularly shaped regions

Forested regions and lakes generally have irregular boundaries. In this portion of the tutorial, you will be asked to find the area of an irregularly shaped object.

Inscribed/Circumscribed Rectangle Method

In this method you overestimate the area of a region with one rectangle and underestimate the area of a region with a smaller rectangle. Averaging the areas gives a quick estimate of the area of the irregularly shaped region.

For our example, we will find the area of an off-shore island near Beverly, MA. In Figure 1, a rectangle defines a region with area larger than that of the island.



Lines: 272 - 301
Columns: 347 - 370
L,C: ,

Figure 1

To determine the coordinates of the selected region, under the **Options** menu, select **Show Selection Coordinates**. Note the Coordinates in the figure.

Consider the screen to be a large coordinate graph with (0,0) in the upper left corner, (512,0) in the upper right hand corner, (0,512) in the lower left, and (512,512) in the lower right as shown in Figure 2. Lines are horizontal and can be thought of as rows in a matrix. Columns are vertical and can be thought of as columns in a matrix.

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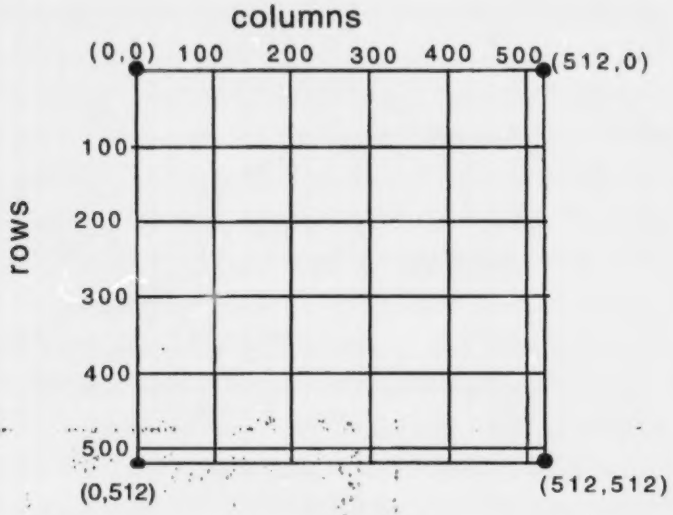
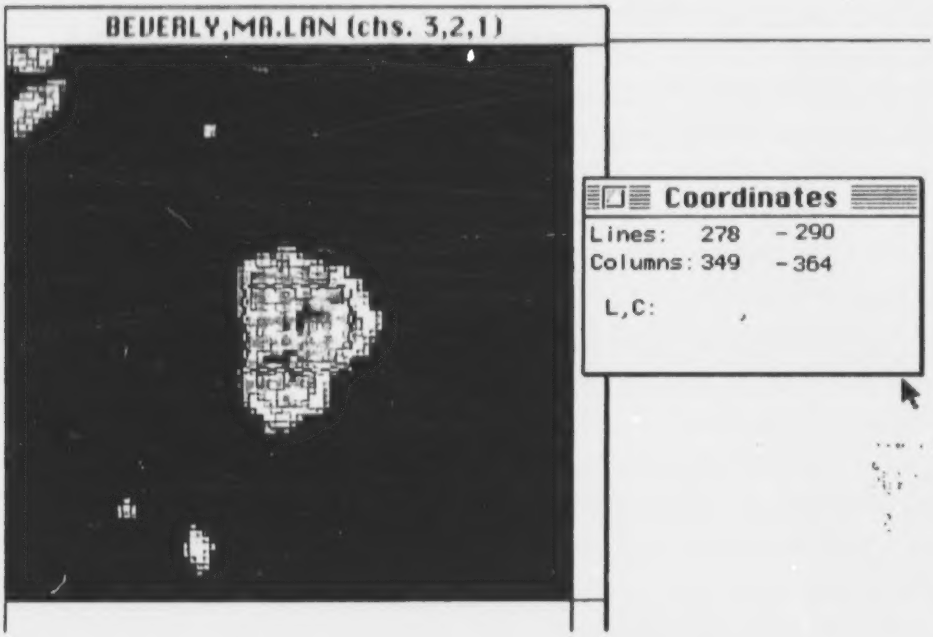

columns
(0,0)
100
200
300
400
500
(512,0)
rows
100
200
300
400
500
(0,512)
(512,512)

Figure 2

The coordinates in Figure 1 are lines 272 to 301 and columns 347 to 370. Since 301 - 272 = 29, the highlighted rectangle is 29 pixels in length (vertical) or 30 meters x 29 = 870 meters. The difference of the columns is 370 - 347 = 23 pixels. Multiplying, 30 meters x 23 = 690 meters. The area of the highlighted rectangular region is 870 meters x 690 meters or 600,300 square metes.

Follow the same procedure to determine the area of the highlighted region in Figure 3 on the following page.



Lines: 278 - 290
Columns: 349 - 364
L,C: ,

Figure 3

(290-278) x 30 = 360 meters; (364 - 349) x 30 = 450 meters. The area is 360 meters x 450 meters = 162,000 square meters.

Use the information just computed to determine the area of the island.

(600,300 + 162,000)/2 = 381,150 square meters. Assuming one digit accuracy, the area is approximately 400,000 square meters.

This concludes the basic portion of the MultiSpec tutorial. You should now be able to use what you have learned here to investigate images of your own area. There are many other capabilities of this software program that are addressed in the advanced portion of this tutorial that will follow.

Installing MultiSpec© on Your PC

- Turn on your computer.
- Create a **MULTSPEC** directory on your hard drive for the files.
- Copy The **MULTSPEC.EXE** (no math coprocessor) and/or **MULTSPEP.EXE** (math coprocessor) file to the new directory on the hard drive.
- Insert the disk labeled **Beverly,MA**.
- Copy the **BEVERLY.LAN** file to the **MULTSPEC** directory on your hard drive that contains the **MultiSpec** program file.
- Copy the **BEVERLY.STA** file to the **MULTSPEC** directory on your hard drive that contains the **MultiSpec** program file.
- **Start Windows**
- **Create a new Program Group**

1. From the **File menu**, choose **New**. The **New Program Object** dialog box appears.
2. Select the **Program Group** option and click on **OK**.
3. In the **Program Group Properties** dialog box, type **MultiSpec** in the **Description** box.
4. Click on **OK**. You should now have a new group icon in the **Program Manager** window.

- **Create a new Program Item**

1. **Open** the **Program Group** you just created.
2. From the **File menu**, choose **New**. The **New Program Object** dialog box appears.
3. Select the **Program Item** option and click on **OK**.
4. In the **Program Item Properties** dialog box, type **MultiSpec** in the **Description** box.
5. In the **Command Line** box, type the path, program file, and extension for the MultiSpec program.

   For example: **C:\MULTSPEC\MULTSPEP.EXE**
6. In the **Working Directory** box, type the path and directory where the files are located.

   For example: **C:\MULTSPEC**
7. Click on **OK**. You should now have a new item icon in the new **Group** window.

- You can now start the MultiSpec program the same way all Windows applications are started, by double-clicking on the **Item icon**.

Note: If problems arise with the Windows setup or the MultiSpec program will not start, consult the Windows manual that came with your computer for further guidance and troubleshooting.

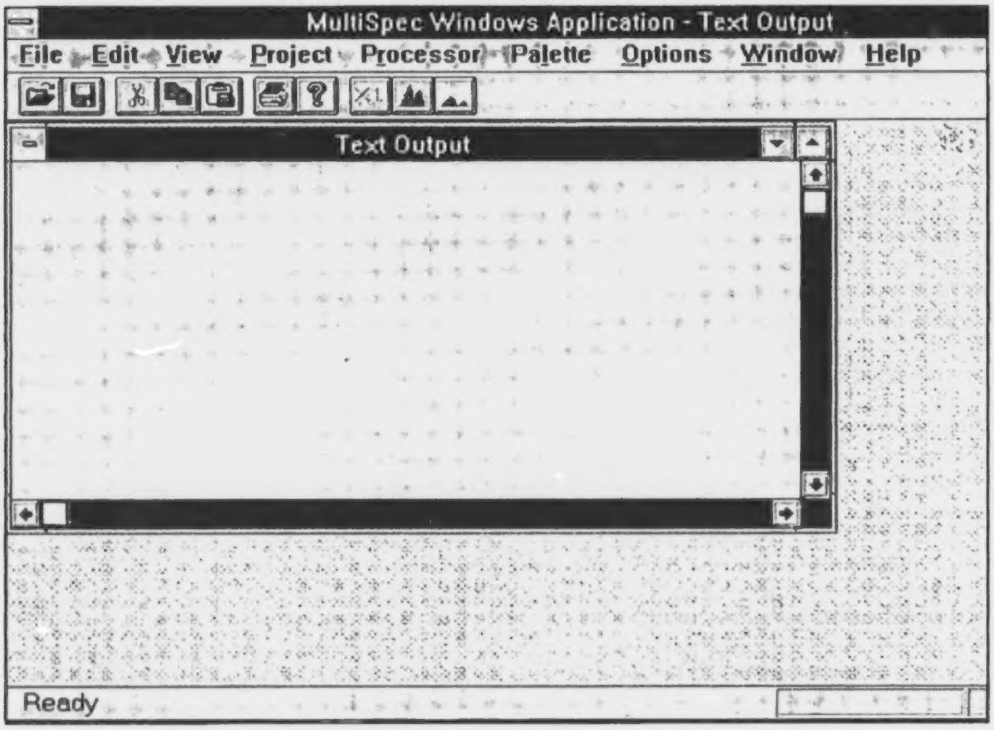
Investigating a satellite image

Materials needed:

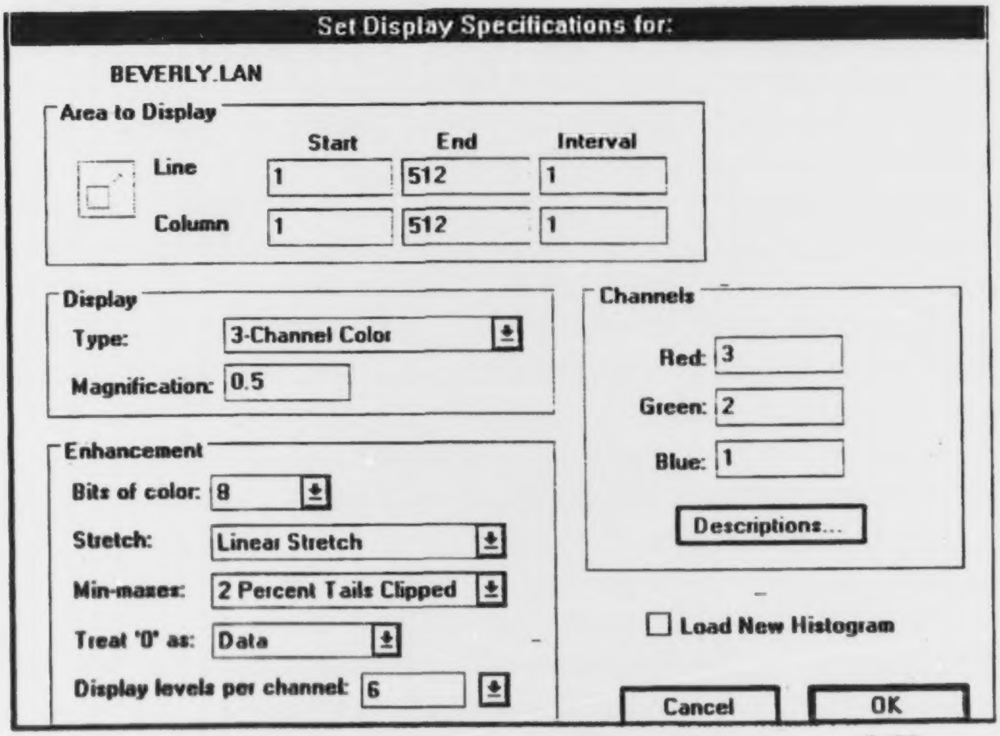
PC with **BEVERLY.LAN** image installed

Getting Started:

- After turning on your computer, start Windows.
- Double click on the **MultiSpec Group icon** to open the window.
- Double click on the **MultiSpec Item** icon to start the MultiSpec program. The window labeled **Text Output** should appear. Your screen should be similar to the one shown in the diagram


MultiSpec Windows Application - Text Output
File Edit View Project Processor Palette Options Window Help
Text Output
Ready

- Pull down the **File** menu and select **Open Image**. Double click on **BEVERLY.LAN** to select that Landsat satellite image.
- You should now have a dialogue box entitled **Set Display Specifications for 'BEVERLY.LAN'** displayed on your screen.



BEVERLY.LAN

Area to Display

	Start	End	Interval
Line	1	512	1
Column	1	512	1

Display

Type: 3-Channel Color
Magnification: 0.5

Enhancement

Bits of color: 8
Stretch: Linear Stretch
Min-maxes: 2 Percent Tails Clipped
Treat '0' as: Data
Display levels per channel: 6

Channels

Red: 3
Green: 2
Blue: 1

- Click on the box labeled **Display Type** and be sure **3-Channel Color** is selected.
- **Leave 8 bits of color selected!** (If you have more than 8MB of RAM available and you have 24 bits of color available on your computer, you may do the following: Click on the Bits of color box and select **24**.) If you select 24 bit color when you do not have enough memory, you will receive messages telling you "**not enough memory is available**" and your display image will have problems. This message is referring to the amount of memory in the computer.
- Under **Channels** set **Red** box to **3** , **Green** box to **2** , **Blue** box to **1** and click **OK**. To edit the number appearing by each color, click to the left of the number and, without releasing the mouse button, drag the mouse to the right or double-click on the box. This should highlight the number you want to change. When it is highlighted, release the mouse button. The box should stay highlighted. Now type the number you wish to enter in the box. You may use the **Tab** key to move between boxes on the screen.
- Click **OK**. The image display should now appear in the upper left of your screen. At x.500 magnification you can see the entire image at once.

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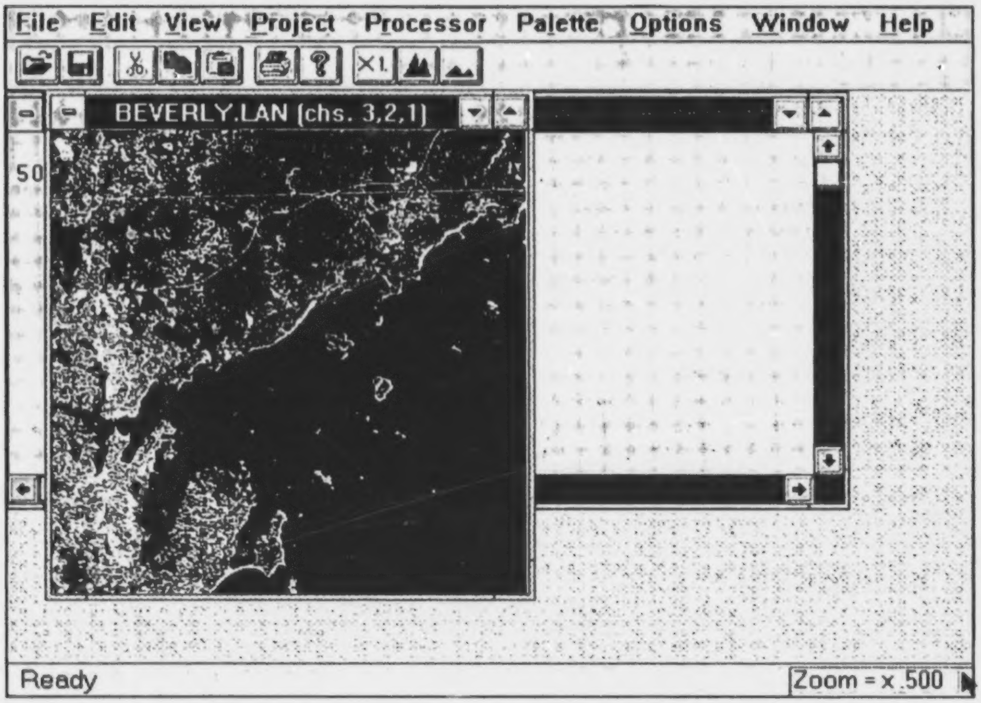
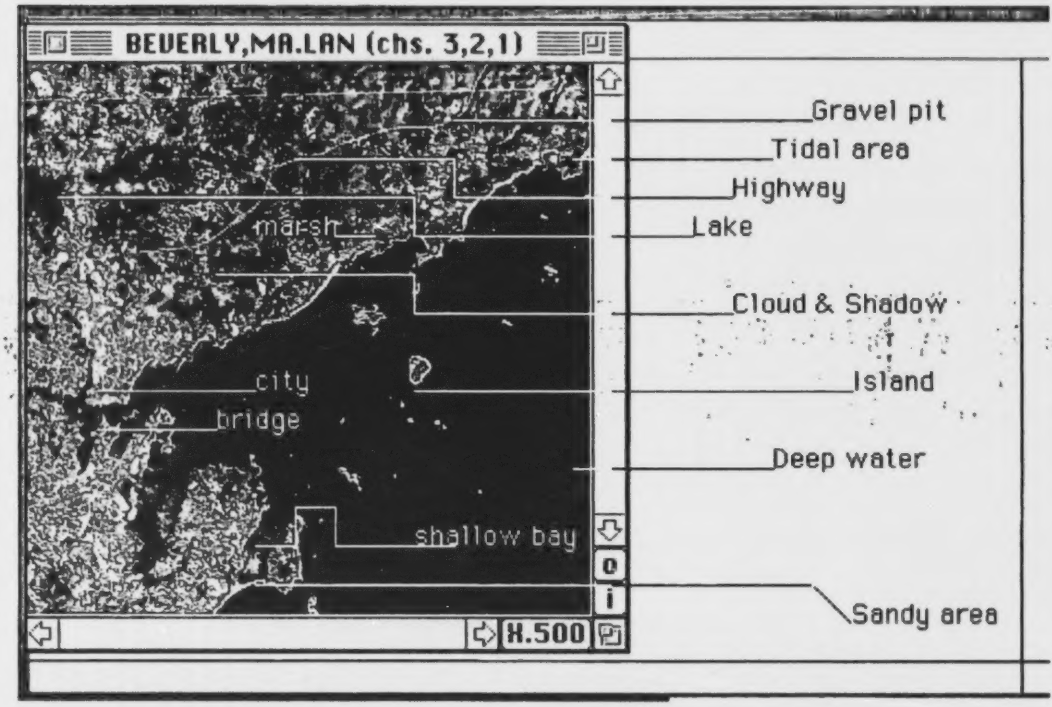

File
Edit
View
Project
Processor
Palette
Options
Window
Help
X1.
BEVERLY.LAN (chs. 3,2,1)
50
Ready
Zoom = x .500

- To enlarge the window, click on the lower right corner of the image window and drag the box to the right and down. In the lower right hand corner of the application window, is a box that shows **Zoom=x.500**. This box depicts the current magnification factor being used to display the image. The right three boxes in the toolbar, located directly above the image window, control the magnification factor. The box shown as **X1.**, when clicked on, will always return the factor to 1. Click on this box now. The box in the lower right hand corner of the application window should now read **Zoom=x1.0** and the image should enlarge and fill the viewing window depending on how much you enlarged the image window. You will have to scroll up or down to see the whole image when the magnification factor is **x1.0** unless your monitor is 17-inches or larger.

1. Try to identify roads, bridges, lakes, towns, regions with trees, beaches, marshy regions near the shore, shallow ocean waters, etc. (The image below is to assist you and **is not** a Windows screen.)


BEVERLY,MA.LAN (chs. 3,2,1)
marsh
city
bridge
shallow bay
Gravel pit
Tidal area
Highway
Lake
Cloud & Shadow
Island
Deep water
Sandy area
o
i
X.500

2. Zooming:

To the right of the **X1.** box on the toolbar is a box with large mountains to **zoom in** with and a box with small mountains to **zoom out** with. These zoom boxes allow you to zoom in and out from the current image scale. (From now on the large mountain box will be abbreviated as i and the small mountain box as **o**.) The box in the lower right hand corner of the application window (hereafter referred to as the zoom box) will change every time the i or o box is clicked on the toolbar. Click the i once. Now click on i many, many times. You should eventually see the image appear as a mosaic of squares (pixels) on the screen. Before proceeding to #3, click on the **X1.** box. The image should now be full size and the zoom box should read **x1.0**.

Questions:

a. What do you notice about the length of objects when you zoom in? when you zoom out?

Objects increase/decrease in length proportionately with the zoom factor.

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b. What information is gained when you zoom in or out? What information is lost?

When you zoom in, you can focus on a smaller region. Eventually the image becomes a mosaic of pixels. When you zoom out, you can see a larger region at once.

3. Zoom Box:

You also can zoom in on a specific region by boxing the region and zooming. Place the mouse pointer at the upper left corner of the area you wish to box. Then click and hold the mouse button while moving the mouse to the right and down. When you have boxed off the desired area, release the mouse button. Notice that the region you selected is delineated by dashed lines. Click on the **i** box. You can continue to zoom in on the selected region by continuing to click on **i**. What do you observe? If the zoom box is not square, do the image proportions appear to change? Give reasons for your answer.

The proportions of a figure do not change. Lengths all change proportionately. Shape stays the same, size changes.

To zoom in or out by tenths, hold down the **Ctrl** key while clicking on the i or o box.

Return to the full image by clicking on the **X1**. box so the zoom box reads **Zoom=x1.0**.

4. Panning:

In order to move (pan) around the image, you can use the scroll bars.

Investigating color in a satellite image

Image Display:

Under the **Processor** menu select **Display Image**.

Please read the following information about color and Landsat satellite images. The colors red, green, and blue refer to the computer monitor color guns. (They apply red, green and blue light to each pixel in specific intensities.) The **channels** (often called **bands**) refer to bands of reflected light sensed by the satellite from the objects in the image. Band 1 is reflected blue light, band 2 is reflected green light and band 3 is reflected red light. Red, green, and blue are the primary colors of visible energy. Different hues (shades) of color are obtained on the screen when color guns apply different intensities of red, green, and blue light to the same pixel. For example, equal intensities of red and green light produce yellow; equal intensities of blue and green light produce cyan; and equal intensities of blue and red light produce magenta. Bands 4 and 5 receive reflected near infrared and mid infrared energy, respectively.

We will use the following red, green, and blue (RGB) channel settings in order to get a feel for different channel (band) combinations.

True color images - This band combination presents an image as it would appear to the human eye, looking back from space.

Red	3 (the visible red band)
Green	2 (the visible green band)
Blue	1 (the visible blue band)

Other band combinations result in images that do not appear as they would to the human eye. These images are called **false color images**. Enter the following band combinations and observe the results.

A. The band combination below mimics infrared aerial photographs. Plant material, which reflects a great deal of infrared energy, will stand out as bright red with this band combination. This is useful to people studying forests.

Red	4 (the near Infrared band)
Green	3 (the visible red band)
Blue	2 (the visible green band)

B. This band combination is especially good for separating trees and grassland. The conifer or evergreen trees appear as intense dark green, deciduous trees appear as medium green, and grassland appears as light green or yellowish green.

Red	5 (the mid Infrared band)
Green	4 (the near Infrared band)
Blue	2 (the visible green band)

Use the computer image of **BEVERLY.LAN** for the following activity.

Locate the features in the chart below using each of the Red, Green, Blue (RGB) channel settings listed. Record the color of each feature under each channel (band) combination. RGB 321 means assign Channel 3 to the red color gun, Channel 2 to the green color gun and Channel 1 to the blue color gun. TO CHANGE COLOR GUN ASSIGNMENTS PULL DOWN THE **PROCESSOR** MENU AND SELECT **DISPLAY IMAGE**.

Trouble shooting hints:

If, by mistake, you pull down the File menu and select open image, you will have to correct ALL settings, instead of just the color assignments. To do this, go back to the GETTING STARTED directions to be sure you do this correctly.

If you end up with a very tiny image it means you selected a small piece of the image by mistake and asked to have it displayed. Under the **Processor** menu select **Display Image**. Click on the small box in the upper left hand corner to the left of the words: **Line** and **Column**. This will return the image to the full 512 by 512 pixel display.

Complete the chart, recording the color of each feature under each channel (band) combination.

	RGB	**RGB**	**RGB**
	321	432	542
-Beaches			
-Highways			
-Regions with trees			
-Ocean			
-Cities or towns			

Try other channel (or band) combinations and write your observations.

Reference Page

MultiSpec Bands and Their Uses

Band	Principal applications
1 Blue visible light	Useful for mapping water near coasts, mapping forest types, differentiating between soil and plants, and identifying human made objects such as roads and buildings (cultural features).
2 Green visible light	Useful for differentiating between types of plants, determining the health of plants, and identifying cultural features.
3 Red visible light	Useful in differentiating between plant species differentiation and identifying cultural features.
4 Near-Infrared energy	Useful for determining plant types and plant health and for seeing the boundaries bodies of water.
5 Mid-infrared energy	Useful for distinguishing snow from clouds and determining vegetation and soil moisture content.
6 Thermal- infrared energy	(Not included on Landsat Unit disks) Useful in determining relative temperature and determining the amount of soil moisture.
7 Mid-Infrared energy (longer wavelength than band 5)	(Not included on Landsat Unit disks) Useful for differentiating between mineral and rock types and telling how much moisture plants are retaining.

Reference: Lillesand, Thomas M. & Kiefer, Ralph W. (1987), *Remote Sensing and Image Interpretation*. 2nd Edition. New York: John Wiley and Sons. P. 567.

Color My World

Preparation Reading:

Previously you changed the colors on the computer image. When you change the colors, objects may be distinguishable as different colors or become indistinguishable when they blend with the color of other objects around them. The five channels on the images portrayed by the computer imaging program *MultiSpec* contain data from one of five different bands of the electromagnetic spectrum. For each of the five bands, Landsat 5 senses reflected light or energy and assigns a reflectance number to represent the brightness level.

Three of these bands are in the visible range: channel 1 is blue reflected light, channel 2 is green reflected light, and channel 3 is red reflected light. Reflected red, green, and blue light are all useful for distinguishing between human made objects, such as roads and buildings, and natural features, such as rivers, lakes, and mountains.

The other two channels, channels 4 and 5, are in the infrared range, invisible to the human eye. Reflected infrared energy is useful if you wish to determine plant types, determine plant health, distinguish between snow and clouds, or identify mineral and rock types. When you selected different numbers for 3-channel color for **BEVERLY.LAN**, you asked the computer to display three bands of the electromagnetic spectrum.

You can display an image in 1-channel color. Your image will then display brightness levels of only one band of the electromagnetic spectrum, such as red visible light or near infrared energy.

In this lesson you should try to become comfortable with categories of objects based on their reflectance in the different bands of the electromagnetic spectrum. This will help you better understand the Landsat 5 imagery.

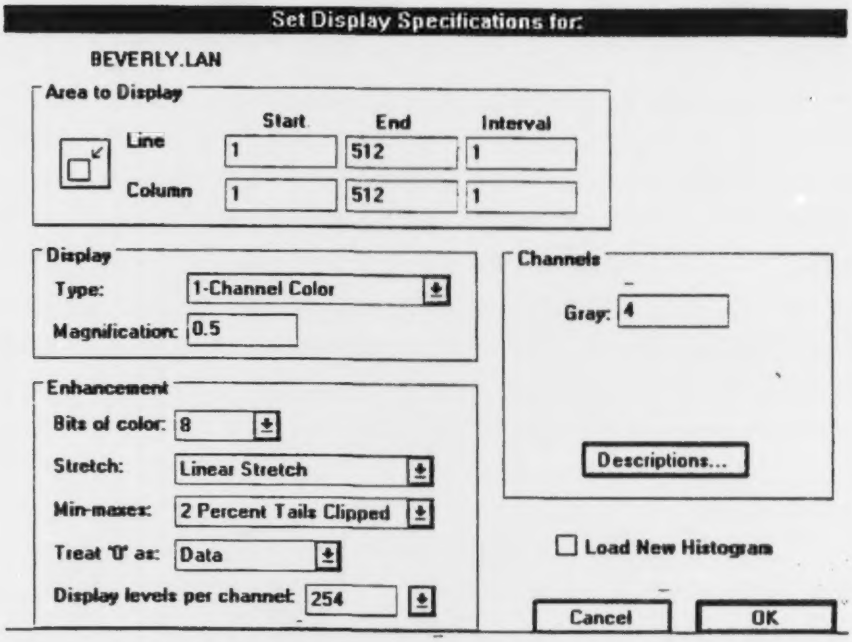
Materials you will need:

Two PC computers with MultiSpec and the **BEVERLY.LAN** image on each.

Each group will need to team with another group and use both computers. If you are fortunate and have one computer available for each student or pair of students, you may want to do this activity in a larger group using the three computers. This activity can also be accomplished on one computer if you have enough memory to open multiple copies of the **BEVERLY.LAN** image.

We will explore the connection between electromagnetic energy and the channels which can be selected in the **Display Image** option under **Processor** in the MultiSpec menu. You will probably want to keep handy the "Reference Page: MultiSpec Bands and Their Uses".

- If you are restarting your computer, follow the first few steps in GETTING STARTED to get to the dialogue box entitled **Set Display Specifications for BEVERLY.LAN.**
- Click on the box labeled **Display type** and select **1-channel color.**
- Click on the box labeled **Bits of color** and select **8 or 24** if you have the required memory.



Set Display Specifications for:

BEVERLY.LAN

Area to Display

	Start	End	Interval
Line	1	512	1
Column	1	512	1

Display

Type: 1-Channel Color

Magnification: 0.5

Enhancement

Bits of color: 8

Stretch: Linear Stretch

Min-maxes: 2 Percent Tails Clipped

Treat '0' as: Data

Display levels per channel: 254

Channels

Gray: 4

☐ Load New Histogram

- Now the directions change for the two computers:

- On one computer, type in 4 for the channel (next to the word "Grey"). (Remember to highlight the number to be changed and then type the new number. Backspacing or deleting the old number first does not always work in this program.) Press Enter or click on OK.

  The gray scale image you see represents the reflectance levels

  of one band of electromagnetic energy. What band is that?

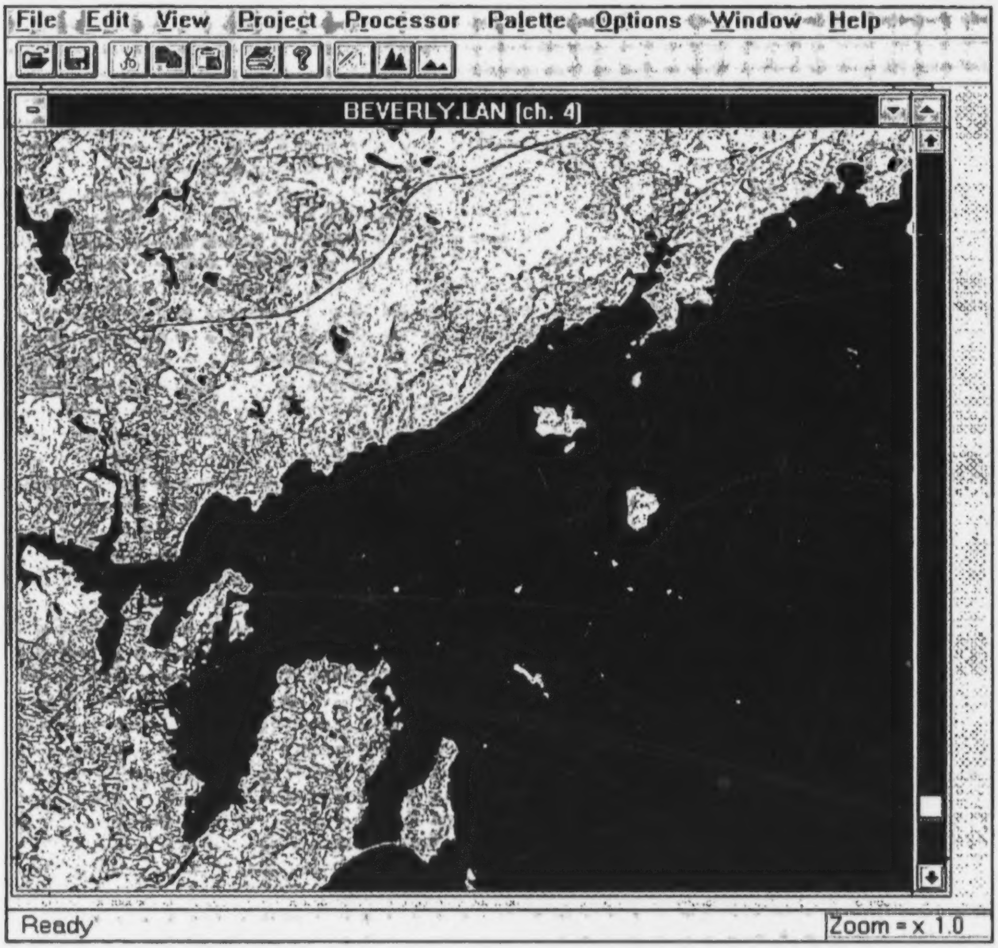
  Is it a visible band?

- On the other computer, type in 3. Press Enter or click on OK.

  What band of electromagnetic energy is transmitted through channel 3? Is it a visible band?

- If you have a third computer, select another visible band to view.

- After the image is displayed, enlarge the viewing window to approximately twice the size. Click on the X1. box in the toolbar to enlarge the image. Your monitor should look similar to the image that follows.


File
Edit
View
Project
Processor
Palette
Options
Window
Help
BEVERLY.LAN (ch. 4)
Ready
Zoom = x 1.0

- Scroll to make sure the display on each computer shows the same region of the image.
- Keep these two images on the screens of the respective computers, making sure everyone can see both screens. The images will be in shades of gray.
- You will need to change the channels on the computers you are using to answer the questions below. To do that, select the **Display Image** option under **Processor** in the MultiSpec menu and just change the channel number.

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Please read:

If an object has a high reflectance level for a particular band, it appears very bright (nearly white). If it has a very low reflectance, it absorbs most of that band and appears very dark (nearly black). For example if an object reflects more blue light than red light, it will appear lighter in the image for which the selected channel is 1 for blue light than in the image for which the selected channel is 3 for red light.

Answer the following as completely as you can:

1. You should be able to distinguish trees, the railroad bridge between Beverly and Salem, and shallow bays more easily in one image display, but not in the other. Roads are bright in one image and dark in the other. Explain these observations with reference to the red and near-infrared bands of the electromagnetic spectrum.

   Trees absorb red light and appear dark in the red band and can be distinguished from beaches and grasslands. In the near-infrared band the trees appear very bright because they reflect near-infrared energy. They are not easily distinguishable from the grassland.

   The shallow water east of the Beverly-Salem bridge reflects a small level of visible red light and appears lighter than the deeper ocean. All water areas absorb near-infrared energy and mid-infrared energy.

   The railroad bridge reflects red light and is visible in the red band. It absorbs near-infrared energy and is not easily distinguishable in the infrared band.

   Highways reflect red visible light and absorb near infrared energy.

2. List other objects that have either high reflectance of visible red light and low reflectance of near infrared energy or high infrared and low visible red.

   Buildings, often called cultural features because they are human made, reflect visible red light but absorb near infrared energy.

Note: To answer the following questions you will have to change the bands on the computers and make comparisons.

3. Cultural features are human-made features such as roads, buildings, and bridges. What do you notice about their reflectance of visible light and infrared energy? On the computer that displays visible red light, change the channel to visible green (band 2) and then visible blue (band 1) to answer this question.

   Cultural features have high reflectance of all visible light and low reflectance of near-infrared energy.

4. What do you observe about the relative reflectance of a) red, b) blue, and c) green light; and d) near-infrared energy by the ocean? For an extra project, you may want to do some library research to determine why bodies of water appear blue when you actually look at them.

   Bodies of water absorb almost all energy, but blue visible light will reflect more than other bands.

5. What do you observe about the relative reflectance of a) red, b) blue, and c) green light; and d) near-infrared energy by trees?

   Trees reflect low levels of red and blue visible light and slightly higher levels of visible green light. They reflect high levels of near and mid infrared energy.

6. What do you observe about the relative reflectance of a) red, b) blue, and c) green light; and d) near-infrared energy by "cultural features"?

   Cultural features reflect all visible light and low levels of near-infrared energy.

7. There is a cloud over Beverly and several other small clouds in the image. Try various bands to make observations about the reflectance of clouds?

   Clouds reflect all visible light and all infrared energy. This is why cloud free images are important to distinguish surface features of the earth. Clouds "hide" the earth. Radar does penetrate clouds. Landsat 6 that was not successfully launched had a radar sensor.

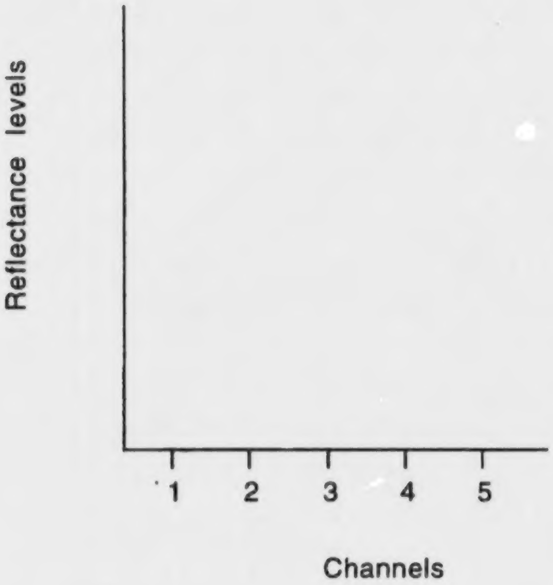
8. Shadows of clouds and lakes appear dark in the image. Try various bands to develop ways to distinguish cloud shadows from lakes.

   Lakes reflect low levels of visible light and essentially no infrared energy. Shadows are "transparent" and reflect whatever is beneath them. This means that if they are over trees, the region in the shadow will reflect high levels of infrared energy.

9. Write a question about color and images and either answer it yourself or have a neighboring group try to answer it. Write the question and answer here.

   Answers will vary.

10. The designer of the chart below did not finish her work.
    a. Insert the scale on the "reflectance levels" axis.
    b. Insert the words that go with the numbers on the "channel" axis.



11. Suppose you had selected a pixel that contained only trees. On the chart in #10, try to predict a channel reflectance value for each band. Use your answer to question 5 for help in answering this question.

Graphing

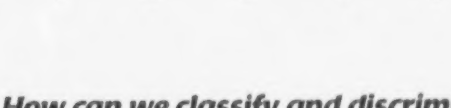
Preparation Reading:

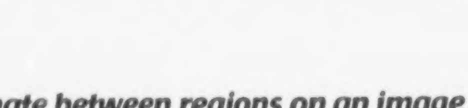
The histograms you will be studying are of the reflectance values at each of the 5 wavelengths the satellite measures. On the horizontal scale the numbers 1 through 5 refer respectively to the blue, green, red, near-infrared, and mid-infrared wavelengths. The vertical scale ranges from 0 (no reflectance) to 255 (maximum reflectance). Sometimes the vertical scale will go beyond 255, but the values plotted never exceed 255. Note that the graph really only has meaning when read at the horizontal positions of 1, 2, 3, 4, or 5. The line segments which connect the points don't represent reflectance values of other wavelengths. They simply make the graph easier to read.

The red line is the average of the reflectance of all the pixels in the selected area. The green lines mark off all reflectance within 1 standard deviation of the average, and the blue lines mark the minimum and maximum values. A formal definition of standard deviation is not developed. You are simply instructed that the green lines contain about 66% of the reflectance in the selected area.

Mathematically the primary emphasis should be on the interpretation of graphs. You will be viewing graphs that are automatically scaled to fill the window. While convenient, this feature can be confusing as the vertical scale can change dramatically from one region to the next. So although two graphs may look the same their vertical scales could be vastly different. This phenomenon highlights the difference between two graphs having the same relative shape but different absolute shapes.

For example, consider the two graphs on the following page, while the relative shapes are about the same, the absolute shapes are very different. The histogram on the left has a dip on band 4 as does the histogram on the right, however, the dip on the histogram on the right is very small compared to the one on the left! Note that the dip on the right actually looks larger than the dip on the left. It is when we look carefully at the vertical scales, however, that we discover that the dip on the left is a change of almost 200 intensity values while the dip on the right is of only 9 intensity values! The dips are in the same relative position on both graphs but of very different absolute sizes.





How can we classify and discriminate between regions on an image using histograms?

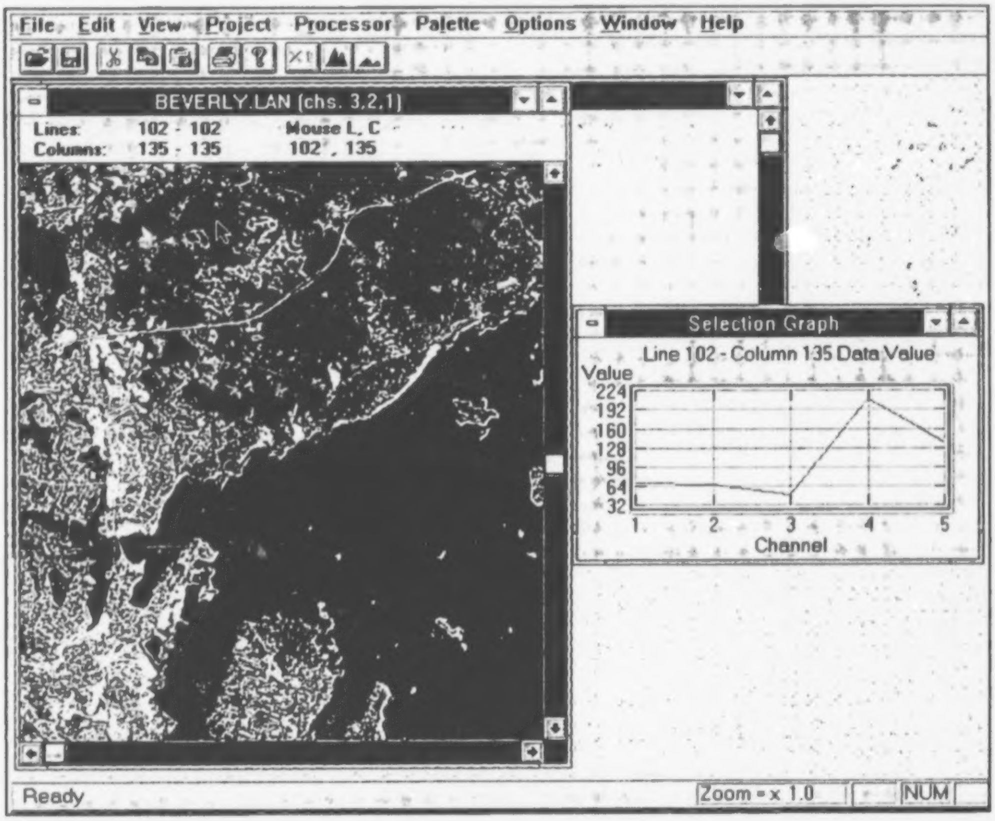
By now you should understand that the images we have been studying are based on numbers that represent the intensity of reflected light at five different wavelengths. Stretching the image and assigning various colors to different wavelengths helped us discriminate between similar looking regions that were in fact different. But some regions still may appear similar on the computer screen even though they represent different objects on earth. In this lesson we learn how to use another tool of the MultiSpec program to help us classify regions, and discriminate between different regions.

Which of These Things Doesn't Belong?

At the computer, start the MultiSpec program and open the image of Beverly, MA if it is not already done. Assign the colors red, green, and blue to bands 3,2,1 to generate a true color image.

Now choose the **Coordinates Bar** from the **View** menu. Now select **New Selection Graph** from the **Options** menu. Click anywhere on the image window to highlight it, and click again on any one pixel of the image.

By re-sizing the windows (lower right corner of a window) and moving the windows around the desktop (drag the window by its title bar) arrange the windows so that they appear similar to the figure which follows.


File
Edit
View
Project
Processor
Palette
Options
Window
Help
BEVERLY.LAN (chs. 3,2,1)
Selection Graph
Line 102 - Column 135 Data Value
Value
224
192
160
128
96
64
32
1
2
3
4
5
Channel
Ready
Zoom = x 1.0
NUM

Lines: 102 - 102 **Mouse L, C**
Columns: 135 - 135 102 , 135

Coordinates Bar

Directly above the image in the figure above is the Coordinates bar. This bar allows you to know exactly what part of the image you are selecting when you click on the image window. The coordinates of the cursor are given as an ordered pair with the line number given first and the column number given second. In this figure the pixel selected is the one at (102, 135). Depending on the magnification factor you are using you may have to use the scroll bars on the image window to find a particular pixel.

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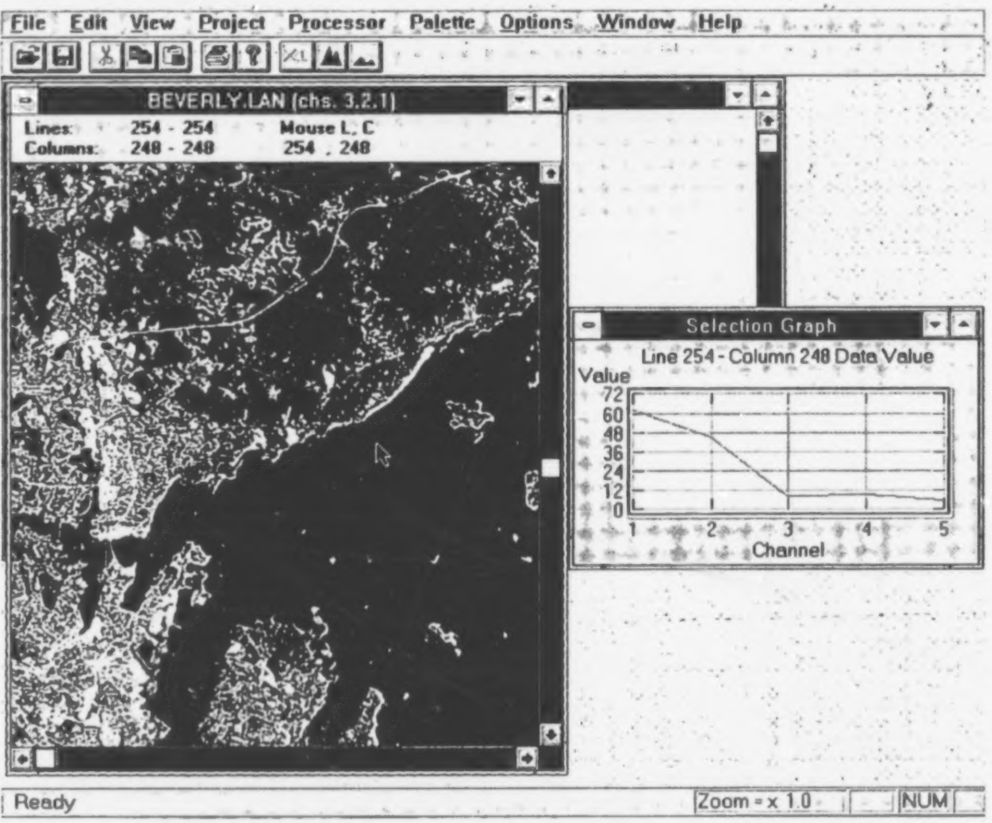
Selection Graph

To the right of the Image window is the Selection Graph window. This is the window you should learn to use during this computer session. It is a graph of the reflectance values of the pixel (or pixels) you have selected. In the above figure the graph is for the pixel located at (102,135).

This graph provides much information. The bottom axis has labels 1, 2, 3, 4, and 5 that correspond to the blue, green, red, near-infrared, and mid-infrared wavelengths that Landsat monitors. The vertical scale corresponds to the numerical value of the reflectance. This scale can range from 0 to 255. A 0 would represent no reflected light and a 255 would represent maximum reflected light. Remember that these values may be the result of stretching the data. The pixel we have selected is brightest in bands 4, and darkest in band 3. This means that the object at this location on the earth is reflecting more near-infrared light than light of the other wavelengths.

Now click anywhere on the image window to activate it. Then click on the pixel with coordinates (L,C) = (254,248) that is down on the ocean. At this point we find reflectances of about 60, 44, 10, 11, and 6. See figure below for an idea of what your screen should resemble.


File
Edit
View
Project
Processor
Palette
Options
Window
Help
BEVERLY.LAN (chs. 3,2,1)
Selection Graph
Line 254 - Column 248 Data Value
Value
72
60
48
36
24
12
0
1
2
3
4
5
Channel
Ready
Zoom = x 1.0
NUM

Lines: 254 - 254
Columns: 248 - 248
Mouse L, C 254 , 248

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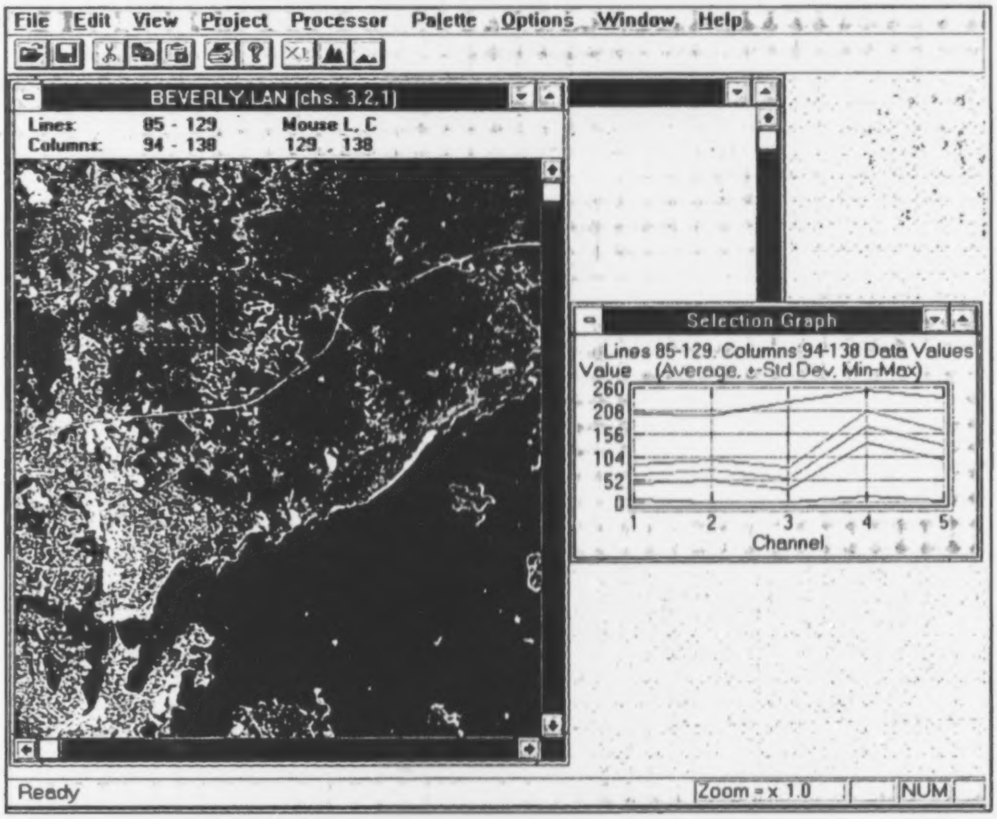
Note that the reflectances are lower at every one of the five bands than for the previous pixel at (102,135). This difference makes sense since we expect the ocean to be darker than ground. If you have ever flown over ocean and trees you will have noticed how the ocean appears almost black while the trees do appear brighter. The fact that water absorbs most all of the energy that falls on it can help us determine if an unknown dark region is water or not.

Now click and drag in the image window to select a rectangle of many pixels. We selected a rectangle with its upper left corner at pixel (L,C) = (85,94) and its lower right corner at (L,C) = (129,138). Try to select these same pixels for the upper left and lower right corners of your rectangle. The result should resemble the figure below.


File
Edit
View
Project
Processor
Palette
Options
Window
Help
BEVERLY.LAN (chs. 3,2,1)
Selection Graph
Lines 85-129, Columns 94-138 Data Values
Value (Average, +-Std Dev, Min-Max)
260
208
156
104
52
0
1
2
3
4
5
Channel
Ready
Zoom = x 1.0
NUM

Lines: 85 - 129 Mouse L, C
Columns: 94 - 138 129 , 138

Note that now the selection graph contains 5 lines. The red line is the average of the reflectance of all the pixels in the rectangle we selected. The green lines mark off a range that contains the middle 66% of the reflectance values. The blue lines indicate where the minimum and maximum values are for the reflectance of all the pixels we selected. For example look at the reflectance on band 4. Of all the pixels

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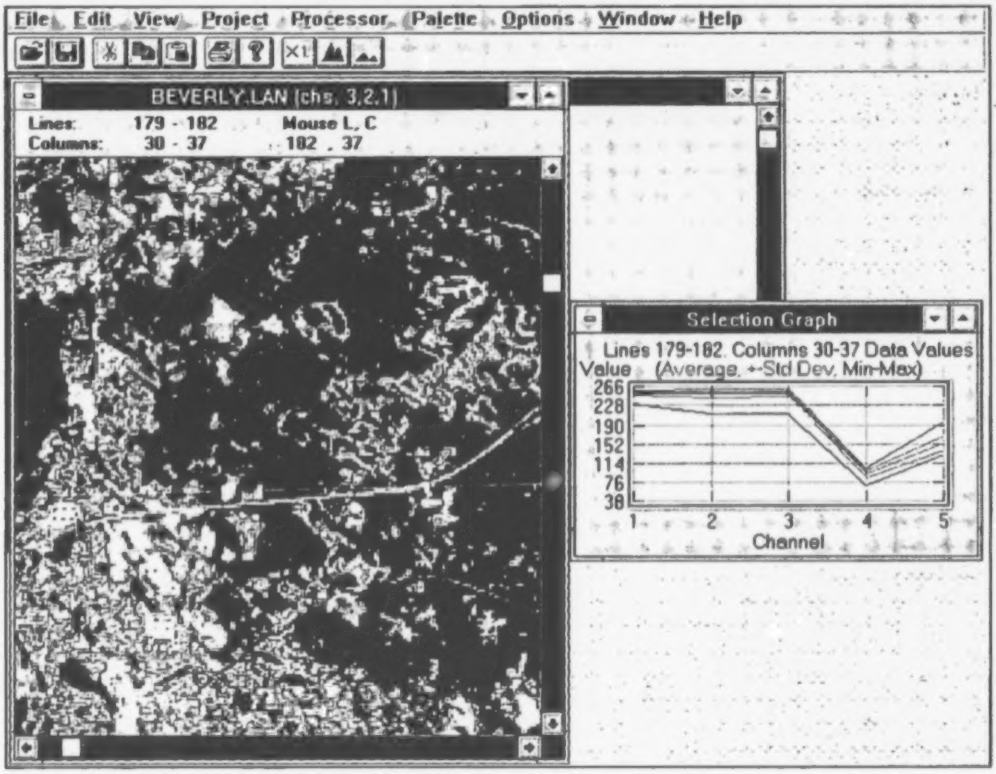
selected in the rectangle the lowest reflectance is about 10, the highest reflectance value is around 255, 66% of the reflectance is between 130 and 208, and the average reflectance is about 160.

Using the Histogram Window to Discriminate Between Different Regions

We can use the histogram window to help us identify similar and different regions. What we will do is find an area of interest and save its histogram to compare with a second histogram of another area of interest. Go to a magnification of **x2.0**. Click and drag the mouse to select a rectangle with upper left corner (L,C) = (179,30) and lower right corner (L,C) = (182,37). Your screen should resemble the figure below.


File
Edit
View
Project
Processor
Palette
Options
Window
Help
BEVERLY.LAN (chs. 3,2,1)
Selection Graph
Value
266
228
190
152
114
76
38
1
2
3
4
5
Channel

Lines: 179 - 182 Mouse L, C
Columns: 30 - 37 182 , 37

Lines 179-182 Columns 30-37 Data Values (Average, +-Std Dev, Min-Max)

Now choose **Keep Selection Graph** from the **Options** Menu. A new selection graph appears and the old selection graph will remain fixed even if you select a new set of pixels. Position the second selection graph below the first graph so that your display resembles the figure below.

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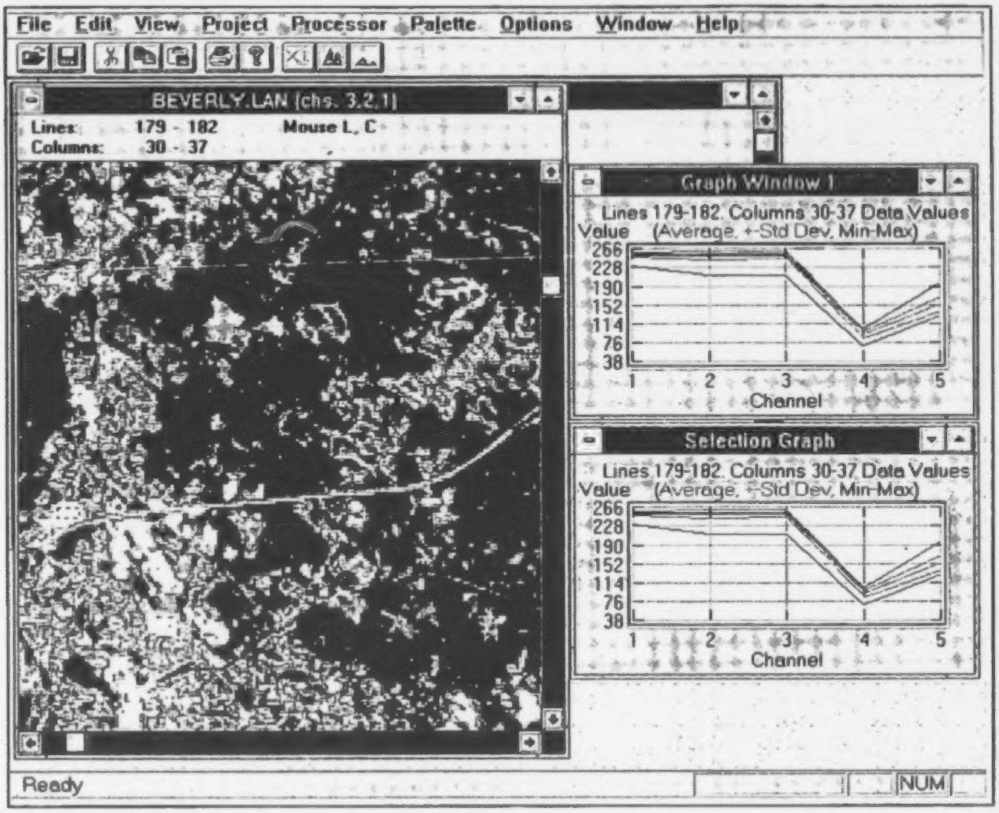
File
Edit
View
Project
Processor
Palette
Options
Window
Help
BEVERLY.LAN (chs. 3,2,1)
Graph Window 1
Lines 179-182, Columns 30-37 Data Values
Value (Average, +-Std Dev, Min-Max)
266
228
190
152
114
76
38
1
2
3
4
5
Channel
Selection Graph
Lines 179-182, Columns 30-37 Data Values
Value (Average, +-Std Dev, Min-Max)
266
228
190
152
114
76
38
1
2
3
4
5
Channel
Ready
NUM

Lines: 179 - 182 Mouse L, C
Columns: 30 - 37

After your screen looks similar to the one in the figure above, click in the image window to activate it, and then click on an image pixel. Note that the top graph stays the same and only the bottom graph changes. Displaying both graphs allows us to compare the histogram of a new region with the saved histogram of the white region visible in the image. This white region is near a road and in the city limits of Beverly. It is very likely that this bright area is caused by light reflecting off large buildings with metal or concrete roofs.

Select just the one pixel at (L,C) = (210,216). This is a pixel in another white region. It is well outside the town of Beverly. Could this white area also be buildings? Let's compare this region's histogram with the first histogram and try to decide if the objects are the same or different. After selecting the pixel at (L,C) = (210,216) your screen should resemble the figure below.

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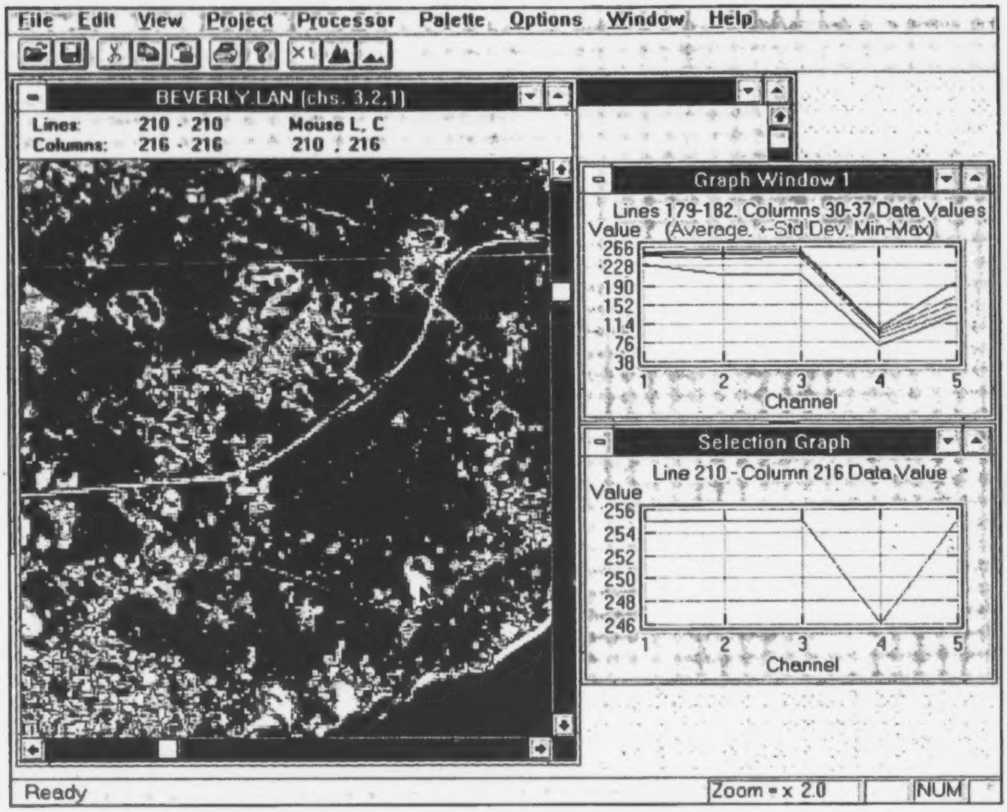
File Edit View Project Processor Palette Options Window Help
BEVERLY.LAN (chs. 3,2,1)
Graph Window 1
Lines 179-182. Columns 30-37 Data Values
(Average, +-Std Dev, Min-Max)
Value
266
228
190
152
114
76
38
1
2
3
4
5
Channel
Selection Graph
Line 210 - Column 216 Data Value
Value
256
254
252
250
248
246
1
2
3
4
5
Channel
Ready
Zoom = x 2.0
NUM

Lines: 210 - 210 Mouse L, C
Columns: 216 - 216 210 , 216

Absolute and Relative Differences

In the figure above the top graph is of the bright object in the city of Beverly and the graph on the bottom is the histogram of the bright image located where the cross-hair cursor is located at pixel (210,216). Are these bright white regions the same? Their graphs look very similar. Both graphs have a "dip" on band 4.

If we were in a hurry we might conclude from the graphs that these objects are the same. If it was really important to know what was at these locations we of course would do some ground truthing. Sometimes though, ground truthing might be expensive or impractical. In these cases a closer examination of the graphs will have to be our only clue to the identity of the objects.

Look more closely at the two graphs. In particular notice the vertical scales. The MultiSpec program automatically chooses the minimum and maximum values for the vertical reflectance scale. The result is that we may be looking at a very small portion of the entire scale. The advantage is that we see only the portion of the scale that is relevant for the region we have selected. The disadvantage is that comparing two graphs with different scales can be confusing.

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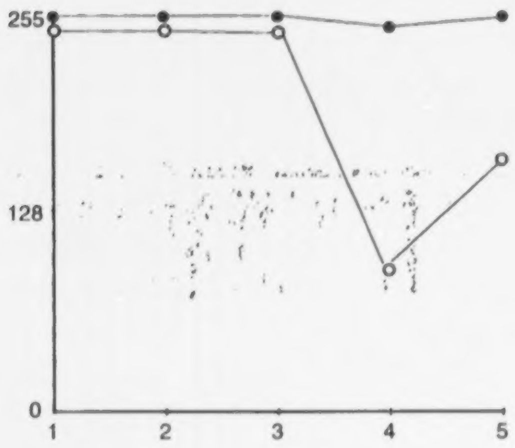
Notice that the top graph drops from the upper 200's on bands 1-3 down to about 90 on band 4. The bottom graph drops from 255 on bands 1-3 to 246 on band 4. This drop is very slight in absolute terms since it is only a difference of 9 reflectance levels. The drop on the other graph is much greater in absolute terms. On the top graph the drop is about 150 reflectance levels! When the differences are viewed absolutely the two graphs are very different.

The reason the graphs initially appeared the same was because we reacted to the similar relative shape of the two graphs. Both graphs do have "dips" at band 4. To make the difference between the graphs more apparent we can plot the two graphs on axes with the same scale as in the figure below.



The object with the large drop in reflectance on band 4 is reflecting very little infrared energy. The histogram of the other object indicates that it is reflecting a lot of energy at all wavelengths measured by Landsat.

The moral of the story is to be sure whether or not the similarity you notice between two graphs is a relative or an absolute similarity (or difference).

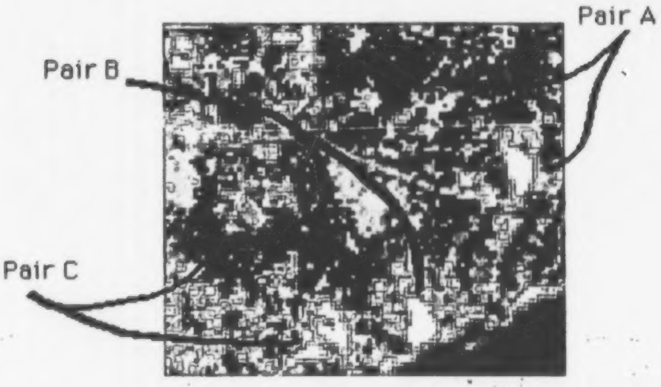
Another Discrimination Exercise

The bright objects to the left of the screen (downtown Beverly) are most likely buildings. We now have evidence (the histograms) that suggest that the bright areas at the right of the screen are not buildings. We have discriminated between two similar appearing but different objects.

But what is that bright feature to the right of the screen?

Use a magnification of **x2.0** and place the unknown bright area near the center of the image window. Notice the three pairs of dark and light regions. The alignment of the three pairs is identical. The dark region is always the same distance away towards the upper left corner of the screen relative to the bright regions. If it hasn't occurred to you already, might these pairs of objects be clouds and their shadows?

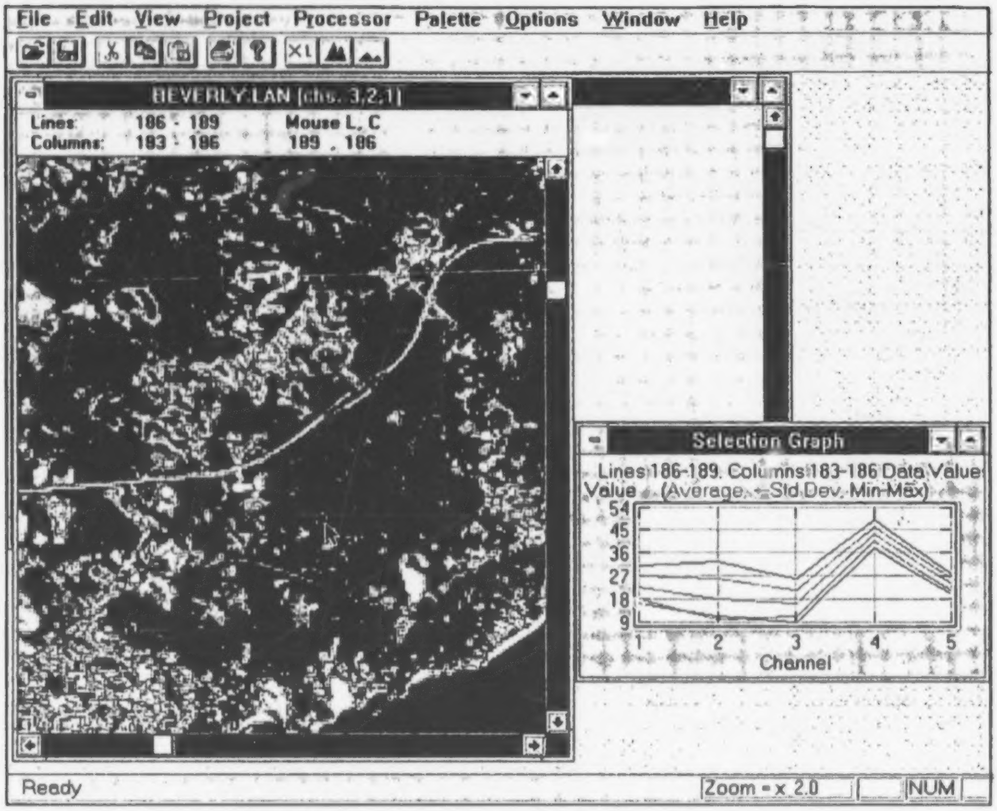
The very similar shapes strongly suggest that we are looking at clouds and their shadows. Note especially how closely the dark object in pair A corresponds to the light object in pair A in the figure below. These must be clouds and their shadows!



But let's be skeptical. What else could these dark regions be? Perhaps they are lakes! Let's get a histogram of one of these dark regions and save it. Then we'll get a new histogram of a known lake for comparison purposes. Here are the steps we can follow to prepare for a new discrimination exercise.

Click in the top graph window to activate it. Now click in the close box (upper left hand corner of window) to close this old histogram.

Click in the image window to activate it. Now select a rectangle of pixels from (L,C) = (186,183) through (L,C) = 189,186). This region corresponds to the dark region that may be a cloud shadow or a lake. You may wish to use a magnification of **X2.0** (or **X1.0**). Your screen should resemble the figure below.


File Edit View Project Processor Palette Options Window Help
BEVERLY.LAN (chs. 3,2,1)
Selection Graph
Value
54
45
36
27
18
9
1
2
3
4
5
Channel
Ready
Zoom = x 2.0
NUM

Lines: 186 - 189 Mouse L, C
Columns: 183 - 186 189 , 186

Lines 186-189. Columns 183-186 Data Value (Average, ±Std Dev, Min-Max)

When your screen resembles the figure above, move the selection graph from the bottom position to the top position (where the old graph used to be). Next choose **Keep Selection Graph** from the **Options** Menu. Now the top graph will remain constant always displaying the histogram of the possible cloud shadow. Re-size and position the new selection graph window below the top one.

Now let's go find a lake. Click on the image window to activate it. Then scroll up the image window and select the rectangle of pixels from (L,C) = (52,237) through (L,C) = (56,243). This region is definitely a lake as verified by ground truthing. The histogram of this lake region should appear in the bottom graph window. After selecting the known lake region your screen should resemble the figure below.

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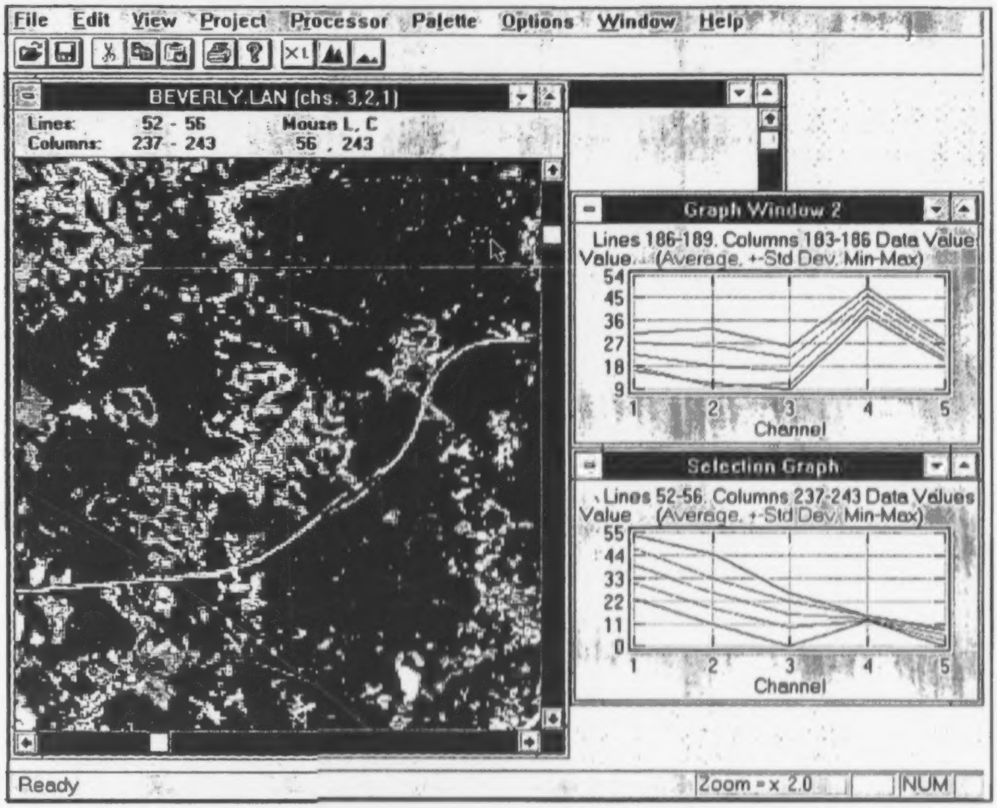
File Edit View Project Processor Palette Options Window Help
BEVERLY.LAN (chs. 3,2,1)
Lines: 52 - 56
Columns: 237 - 243
Mouse L, C
56 , 243
Graph Window 2
Lines 186-189, Columns 183-186 Data Value
Value (Average, +-Std Dev, Min-Max)
54
45
36
27
18
9
1
2
3
4
5
Channel
Selection Graph
Lines 52-56, Columns 237-243 Data Values
Value (Average, +-Std Dev, Min-Max)
55
44
33
22
11
0
1
2
3
4
5
Channel
Ready
Zoom = x 2.0
NUM

Note that the vertical scales on these two graphs are almost identical. We can compare these graphs directly and not worry about making mistakes due to relative similarities that are in fact different in absolute terms.

The histogram at the top is of the suspected shadow, and the histogram at the bottom is of the known lake. Are they the same? No. The lake is absorbing much more near-infrared energy (band 4) than is the shadow. The difference in reflectance on band 4 is about a factor of four (11 for the lake compared with 44 for the shadow). This difference makes sense as we would expect the trees in the shadow to reflect more infrared energy than a lake which is an excellent absorber of infrared energy.

Our exploration has come to an end. We have used histograms to identify clouds and their shadows. Now it's your turn to put histograms to use in helping you discover some interesting features of the Beverly image.

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What's That?!

Using the reflectance histogram tool, explore the Beverly, MA image and see if you can find other examples of regions on the screen image that appear the same to your eyes but have very different histograms. You can display up to 12 histograms on the screen at one time for comparison of features.

Some possible explorations include:

Distinguishing beaches and shore, from very shallow water.

Differences between pavement on roads or parking lots and buildings.

Comparisons between shallow water and deep water.

Exploring similarly colored areas of vegetation that may have different histograms.

Examining in detail the transition from land to ocean. For example look at the histogram for one pixel at a time beginning with (138,397) and moving east through pixels (138,398), (138,399), (138,400), ..., (138,412).

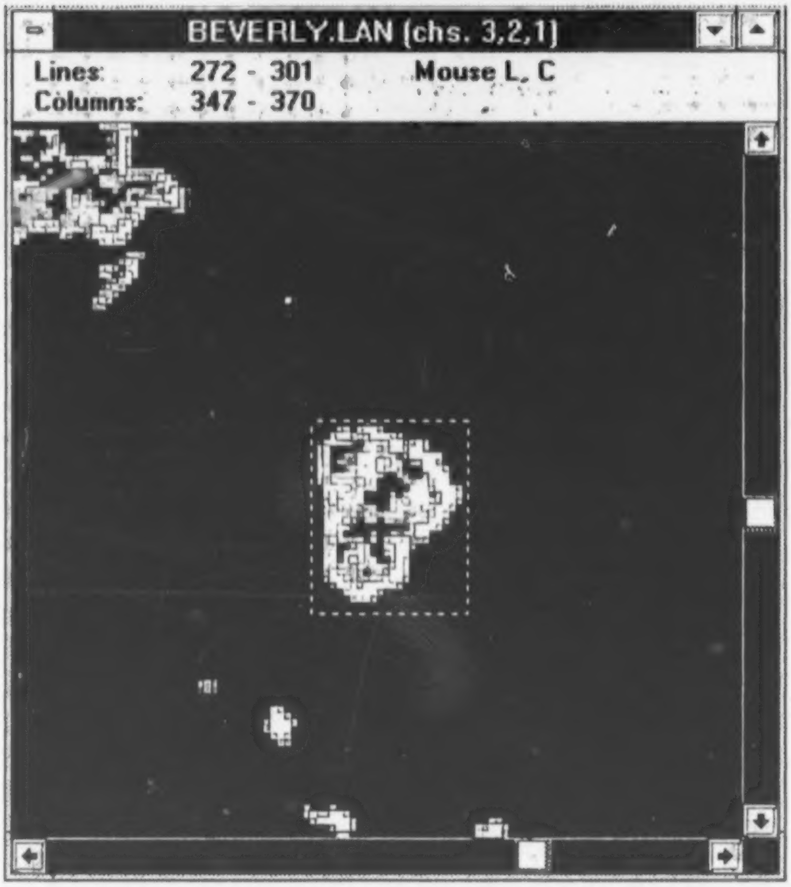
If you find something interesting write a paragraph that provides a guide to exploring the interesting feature you have found. The guide should be complete enough that someone else can reproduce your explorations. Also include in the paragraph your analysis of the objects you are examining. Support any conclusions you make with arguments based on the histograms of the relevant objects. You can also copy histograms to the clipboard and paste them into another application, such as a word processor, to form a library of representative histograms of specific features. You can then investigate an unknown image and identify features by finding similar histograms to those in the library.

Finding the area of irregularly shaped regions

Forested regions and lakes generally have irregular boundaries. In this portion of the tutorial, you will be asked to find the area of an irregularly shaped object.

Inscribed/Circumscribed Rectangle Method

In this method you overestimate the area of a region with one rectangle and underestimate the area of a region with a smaller rectangle. Averaging the areas gives a quick estimate of the area of the irregularly shaped region. For our example, we will find the area of an off-shore island near Beverly, MA. In Figure 1, a rectangle defines a region with area larger than that of the island.



BEVERLY.LAN (chs. 3,2,1)

Lines: 272 - 301 Mouse L, C

Columns: 347 - 370

Figure 1

To determine the coordinates of the selected region, under the **View** menu, select **Coordinates Bar**. Note the Coordinates in the figure.

Consider the screen to be a large coordinate graph with (0,0) in the upper left corner, (512,0) in the upper right hand corner, (0,512) in the lower left, and (512,512) in the lower right as shown in Figure 2. Lines are horizontal and can be thought of as rows in a matrix. Columns are vertical and can be thought of as columns in a matrix.

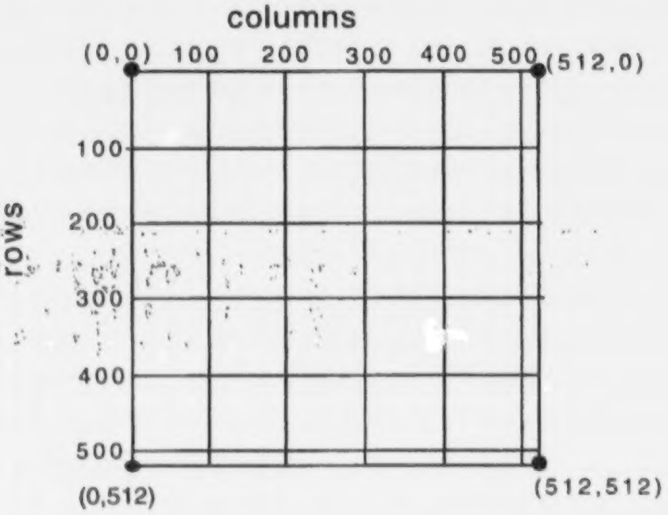


Figure 2

The coordinates in Figure 1 are lines 272 to 301 and columns 347 to 370. Since 301 - 272 = 29, the highlighted rectangle is 29 pixels in length (vertical) or 30 meters x 29 = 870 meters. The difference of the columns is 370 - 347 = 23 pixels. Multiplying, 30 meters x 23 = 690 meters. The area of the highlighted rectangular region is 870 meters x 690 meters or 600,300 square metes.

Follow the same procedure to determine the area of the highlighted region in Figure 3 on the next page.

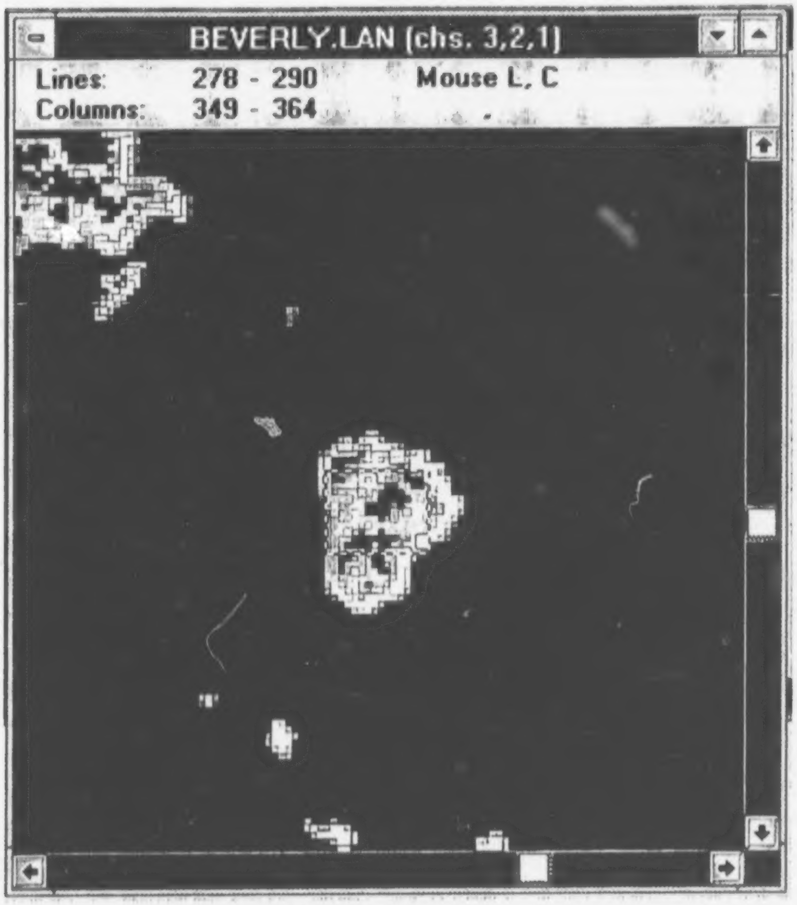


Figure 3

(290-278) x 30 = 360 meters; (364 - 349) x 30 = 450 meters. The area is 360 meters x 450 meters = 162,000 square meters.

Use the information just computed to determine the area of the island.

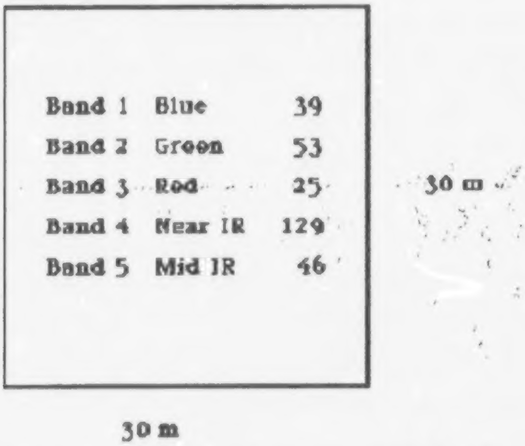
(600,300 + 162,000)/2 = 381,150 square meters. Assuming one digit accuracy, the area is approximately 400,000 square meters.

This concludes the basic portion of the MultiSpec tutorial. You should now be able to use what you have learned here to investigate images of your own area. There are many other capabilities of this software program that are addressed in the advanced portion of this tutorial that will follow.

Unsupervised Clustering Tutorial

Each pixel in your LandSat TM image contains a wealth of information about the surface materials that reflected light from that pixel to the satellite sensors. Each pixel contains a value, from 0 to 255, for each TM band supplied with your image. If, for instance, your image contains data for five bands, then each pixel contains five pieces of data, each ranging from 0 to 255, as shown in the sample pixel diagram to the right.

LandSat Pixel



Band 1	Blue	39
Band 2	Green	53
Band 3	Red	25
Band 4	Near IR	129
Band 5	Mid IR	46

This means that your image could contain 256^5 (that's approximately 1.1 billion) different possible spectral combinations. Each of these combinations does **not** represent a different type of land cover; most of these variations represent very small and, to us, "unseeable" differences in surface reflectance.

In most instances, your computer monitor will be displaying only 256 different colors, hence only 256 different pixels. Even set to "thousands" of colors, only a small part of the many different pixels can be displayed. Even if a monitor could display all the different possible pixels, your eyes simply could recognize only a small number of differences in their appearance.

Because there is a limited number of different land cover types (the Modified UNESCO Classifications scheme, MUC, contains about 130 different types), and no GLOBE study site will have all of those different land cover types, it is necessary to group pixels together into a smaller number of closely related "classes." This process, whereby pixels with similar spectral characteristics are grouped, is done in two different ways, by a supervised and unsupervised classification.

In a supervised classification, you "train" the software to recognize that certain types of pixels represent specific land cover types. This is done on the basis of your knowledge of your own area, and field work you may do. The software then classifies the pixels of your image into the groups you have specified. The MultiSpec tutorial provided with your GLOBE materials contains a section on supervised classification.

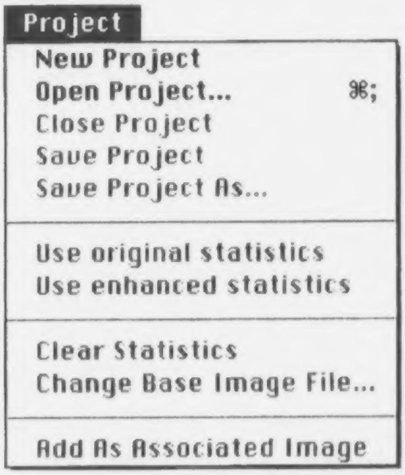
In an unsupervised classification, or "Clustering", we enter the number of groups, or "clusters," we wish to have, and certain other specifications. The software then examines the pixels in the image and groups them according to similar spectral characteristics. These groupings are not made on the basis of land cover, but on the similarity of the spectral characteristics of the pixels.

As part of your preparation of a land cover map for your 15 km x 15 km primary GLOBE study site, it is necessary for you to identify relatively large, homogeneous areas in your image for ground study and later use in a supervised classification. To do this, you will have MultiSpec cluster your image. This will help you locate areas to visit for ground verification studies.

Clustering

To demonstrate clustering, you will use a "sub-set" of the Beverly, Massachusetts image provided with your MultiSpec tutorial. This 101 x 101 pixel sub-image will allow the demonstration process to proceed more quickly than the clustering of a 512 x 512 image, and will allow you to follow exactly the steps outlined in this tutorial.

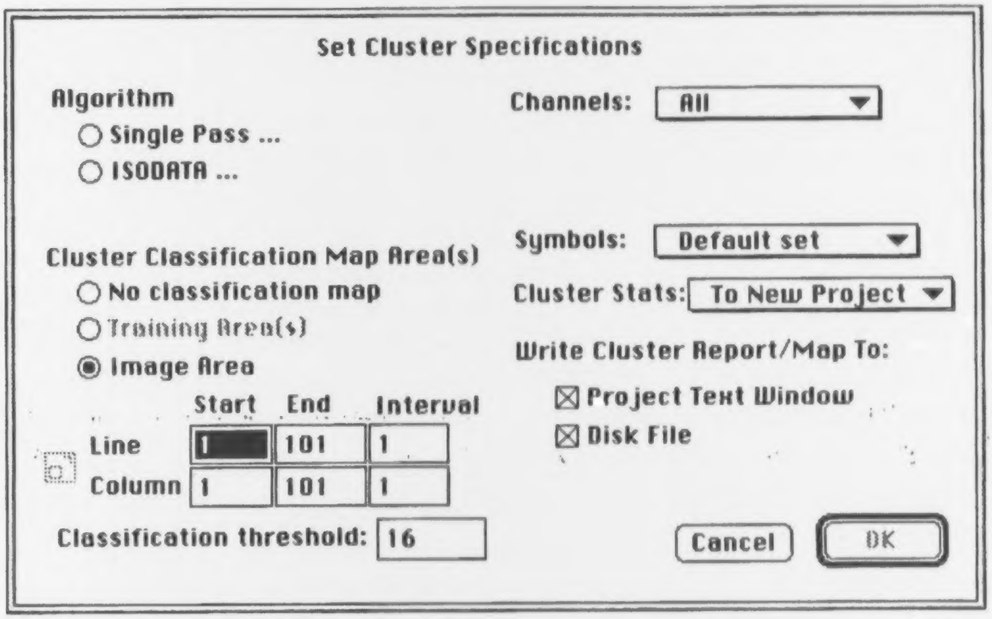
- Launch **MultiSpec** and **Open** the **beverlysubset.lan** image..
- Prom the **Project** menu, as shown to the right, select **New Project**.


Project
New Project
Open Project... ⌘;
Close Project
Save Project
Save Project As...
Use original statistics
Use enhanced statistics
Clear Statistics
Change Base Image File...
Add As Associated Image

Your clustering exercises are saved as projects and, when done, can be opened by **MultiSpec** as **Thematic Images**

- From the **Processor** menu, select **Cluster**. "Clustering" is MultiSpec's terminology for an Unsupervised Classification. As shown on the next page, The **Set Cluster Specifications** window opens. It is in this window that you select a clustering "algorithm' (method by which the software clusters) and enter certain values for the software to use.

You must make certain settings in this window.



Set Cluster Specifications

Algorithm

○ Single Pass ...

○ ISODATA ...

Channels: All ▼

Cluster Classification Map Area(s)

○ No classification map

○ Training Area(s)

● Image Area

	Start	End	Interval
Line	1	101	1
Column	1	101	1

Classification threshold: 16

Symbols: Default set ▼

Cluster Stats: To New Project ▼

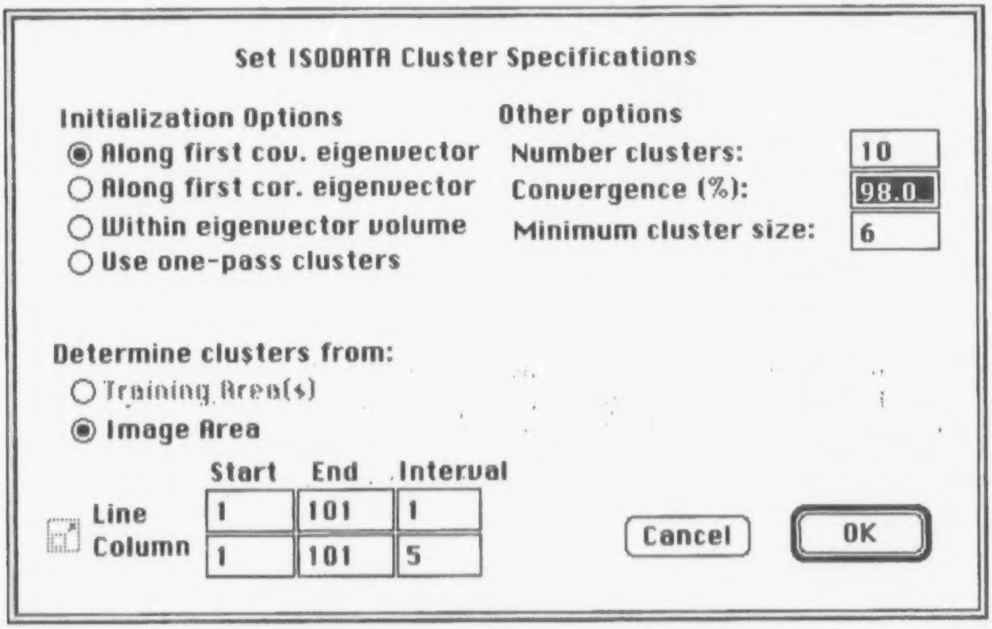
Write Cluster Report/Map To:

☒ Project Text Window

☒ Disk File

- First, be certain to click the **Image Area** button.
- Click to place an "X" in the **Disk File** box. This saves your project to disk.
- Be certain to select **To New Project** from the **Cluster Stats:** menu.
- Lastly, click the **ISODATA** button, as indicated by the cursor in the diagram above. **ISODATA** is the algorithm, or mathematical process, that MultiSpec will use in the clustering process.

A new window, the **Set ISODATA Cluster Specifications** window will open, as shown below.



Set ISODATA Cluster Specifications

Initialization Options

- ● Along first cov. eigenvector
- ○ Along first cor. eigenvector
- ○ Within eigenvector volume
- ○ Use one-pass clusters

Other options

- Number clusters: 10
- Convergence (%): 98.0
- Minimum cluster size: 6

Determine clusters from:

- ○ Training Area(s)
- ● Image Area

	Start	End	Interval
Line	1	101	1
Column	1	101	5

It is in this window that you tell MultiSpec how you want the clustering to proceed. The information you need to provide is:

- Be certain that the **Image Area** radio button is checked, as shown above.
- Select "**Along first cov. eigenvector**." This is the *algorithm*[1] that MultiSpec will use in its clustering
- Leave the settings in the **Other options** boxes unchanged for this exercise.

Notes: "**Number of clusters**" tells the software how many different groups you wish for the classification. The number 10 is used in this tutorial because we are classifying a small area. The number of clusters you will use when you cluster your 512 x 512 image will be discussed later.

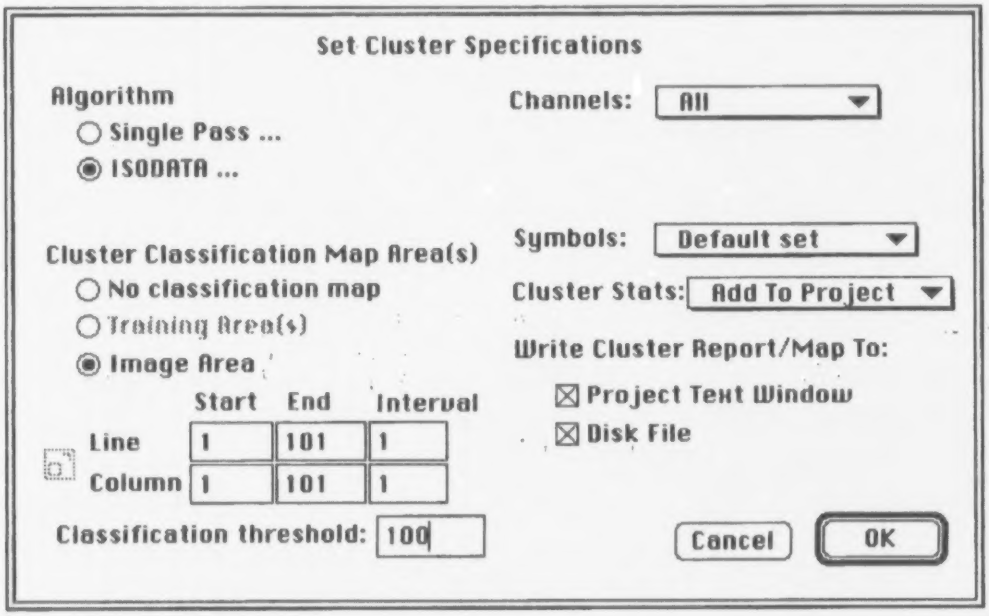
During the classification, the program goes through the data over and over. This is called "iteration." Each iteration is called a "pass". The system makes "passes" through the image until a preset percentage of the pixels in the image are not changed during the pass. The clustering then ends. This percentage is called the "**Convergence.**"

"**Minimum cluster size**" tells the system the smallest sized area to work with. Areas smaller than this minimum size will not be clustered.

---

[1] For a discussion of MultiSpec's algorithms, see "An Introduction to MultiSpec," by David Landgrebe and Larry Biehl, *Purdue Research Foundation*, 1995. This document may be downloaded from the Purdue/LARS WWW site at http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/

- After you have made these settings, click **OK**.
- The **Set Cluster Specifications** window appears *again*.



Set Cluster Specifications

Algorithm

○ Single Pass ...

● ISODATA ...

Channels: All

Symbols: Default set

Cluster Classification Map Area(s)

○ No classification map

○ Training Area(s)

● Image Area

Cluster Stats: Add To Project

Write Cluster Report/Map To:

☒ Project Text Window

☒ Disk File

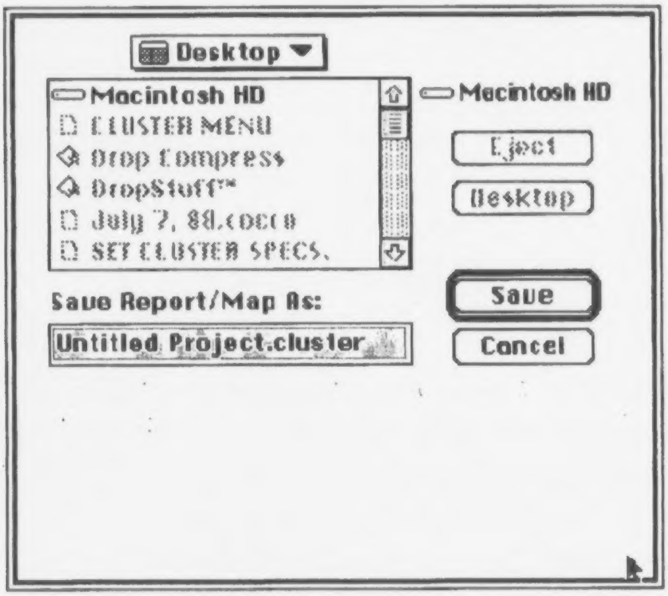
	Start	End	Interval
Line	1	101	1
Column	1	101	1

Classification threshold: 100

- In the lower left-hand corner of the box is the "**Classification threshold:** entry box. Change the value in this box to 100.

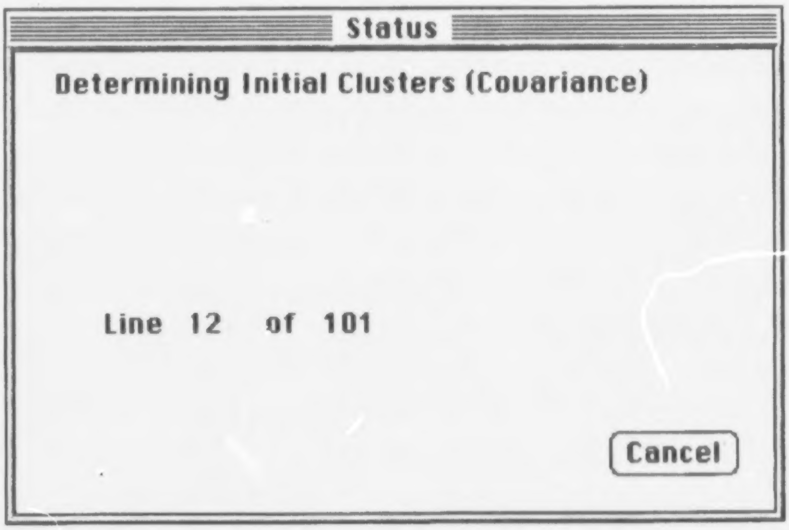
Setting this "threshold" value to 100 forces the system to assign every pixel in the image to one of the clusters. A value of less than 100 specifies the tolerance for assignment of pixels. A value of less than 100 will result in some pixels not being assigned to clusters. In this clustering, you are interested in large, fairly homogeneous areas, so individual pixels of slightly different spectral characteristics dotting the map are unnecessary.

- The **Save File** dialog box appears, as shown below. There is a default name for your classified image file "**Untitled Project.Cluster.**" You should change the Untitled Project" portion to something more descriptive, but leave the "**.Cluster**" extension to tell you what type of file this is.


Desktop
Macintosh HD
CLUSTER MENU
Drop Compress
DropStuff™
July 7, 88.cocca
SET CLUSTER SPECS.
Macintosh HD
Eject
Desktop
Save
Cancel

Save Report/Map As: Untitled Project.cluster

- The system then makes its first pass through the image to initially determine the clusters present, as shown in the **Status** box below.


Status
Cancel

Determining Initial Clusters (Covariance)

Line 12 of 101

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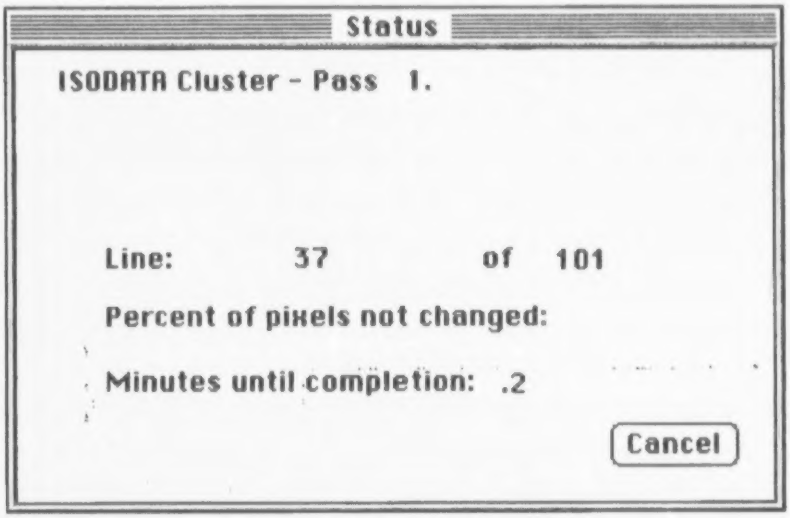
- The first pass clustering **Status** box then appears, as shown. below. During the initial iteration, Pass 1, the "**Percent of pixels not changed**" shows no value. Also, a time is given for completion of the pass.



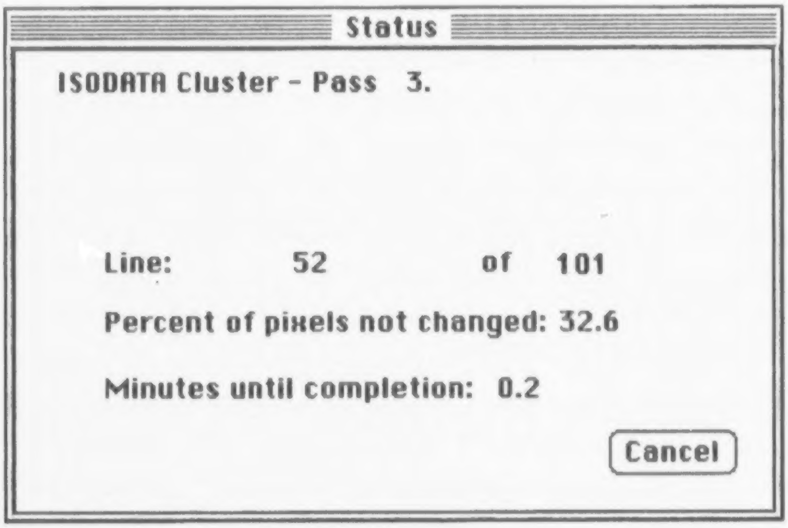
ISODATA Cluster - Pass 1.

Line: 37 of 101

Percent of pixels not changed:

Minutes until completion: .2

- The **Percent of pixels not changed**: entry does not change until the end of Pass 2. As the diagram below shows, a typical value of 30 to 40% will be achieved at this point.



ISODATA Cluster - Pass 3.

Line: 52 of 101

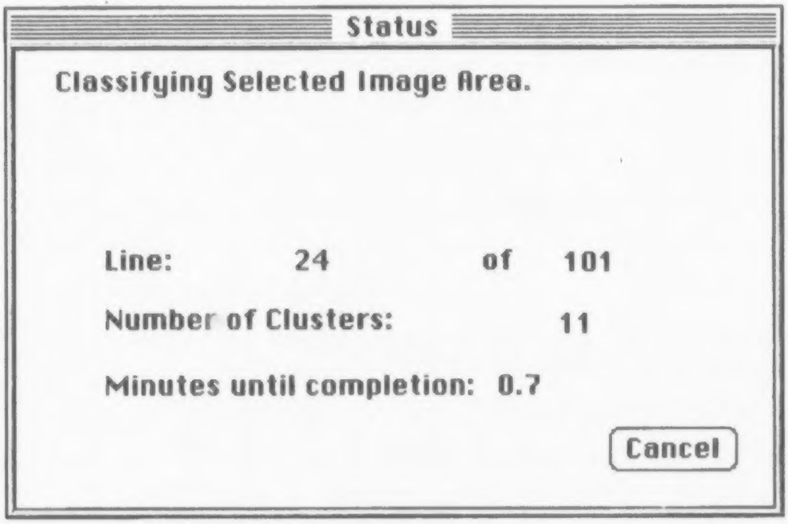
Percent of pixels not changed: 32.6

Minutes until completion: 0.2

- During subsequent passes, the "Percentage of pixels not changed" value increases, until it reaches the value given in the "**Convergence (%)" specification**. The time for each pass to be completed is given in this window.

You can expect the system to make up to 12 to 14 passes to achieve a 98% Convergence. The time required for this process is dependent upon the processing speed of your computer. On a Power Mac 6100/66, running the "fat" version of MultiSpec (the version specially designed for Power Mac) with no other applications open, the process takes about 2 - 3 minutes. On a power book 150 (a very slow machine) the process can take several hours. If your machines are "old and slow" you should plan on the classification being the last exercise of the day. You can then let the processing go on overnight, and the results will be ready the next day.

- If you press "**Cancel**" during a pass, the "**Cancel**" button will darken, but you will see no immediate results. The clustering will be canceled **only when the current pass is completed**.
- After the clusters are determined, the system will display the "**Classifying Selected Image Area**" window, below. Here the system assigns individual image pixels to the clusters it has determined. Notice that it reports 11 clusters, when you specified 10. More on this later.



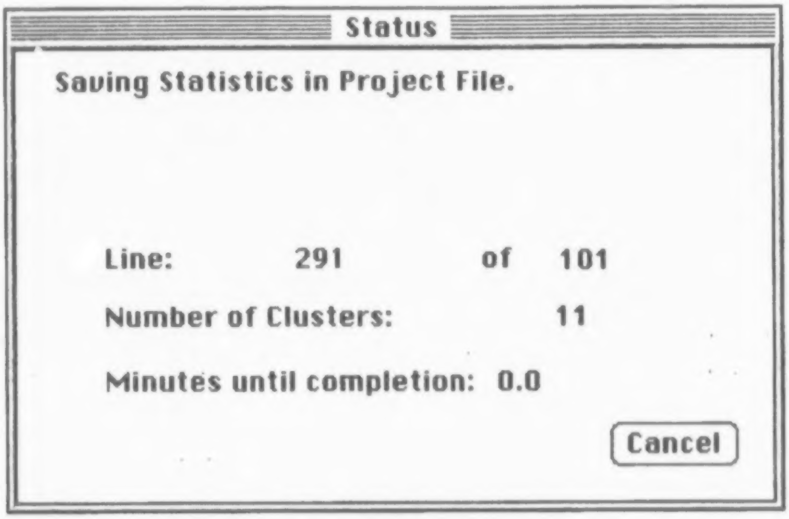
Classifying Selected Image Area.

Line: 24 of 101

Number of Clusters: 11

Minutes until completion: 0.7

- After the clustering is complete, you will see the **Saving Statistics in Project File** window, shown below.



Saving Statistics in Project File.

Line: 291 of 101

Number of Clusters: 11

Minutes until completion: 0.0

- The last message box you get will say "**Output text window being updated.**" The system then returns to your original image.

The Results of Clustering

There are two results of clustering:

A description of clustering activity and a "text map" in the **TEXT OUTPUT** window,

A clustered **Thematic** image.

- From the **Windows** menu, select **Text output**. Scroll to the top of the window, and you will have statistics describing the clustering and its results. A part of the text output for the sample clustering is shown below. In it are listed the number of clusters produced and the average value (mean) of the pixel values for each band in each of the classes.

Final cluster class statistics.

Cluster	Pixels	Channel Means				
		1	2	3	4	5
1	46	238.8	244.5	242.3	162.9	226.7
2	59	215.3	203.2	201.3	118.1	153.9
3	160	155.3	150.4	140.8	142.0	153.2
4	139	118.4	144.4	119.5	227.2	233.9
5	143	112.7	110.4	100.3	138.2	132.1
6	255	89.9	97.8	81.0	182.6	150.7
7	383	67.8	84.5	57.0	232.3	160.9
8	539	60.8	71.5	48.3	198.2	135.5
9	281	60.8	65.3	46.7	153.3	108.8
10	36	69.7	55.7	35.4	19.9	19.6

Number classes = 11

Note that 10 classes are listed, but the system says that 11 classes were used. The 11th class is reserved for "**Thresholded**" classes. These are areas that were not classified into any of the clusters produced by the clustering process. In this clustering, however, you set the threshold at 100, so that the "thresholded" cluster contains no pixels.

Also produced is a text map of the clustered area. The system assigns a number or letter to each of the clusters, and then displays a map of the clustered area using this code. For the clustered Beverly.sub image, the code is shown below.

Classes used:

1: Cluster 1	1
2: Cluster 2	2
3: Cluster 3	3
4: Cluster 4	4
5: Cluster 5	5
6: Cluster 6	6
7: Cluster 7	7
8: Cluster 8	8
9: Cluster 9	9
10: Cluster 10	A
11: Thresholded	

A *portion* of the text map of the clustered area is shown below, in 9 point type. By holding the page at arm's length, you can see that it shows large areas of homogeneous land cover. This text map can be printed and hand colored to show you the location of areas to investigate. However, you will have to print your image in parts; a text map 512 characters wide and 512 lines long would be too large for most printers.

Classification of Selected Area

Lines 1 to 101 by 1. Columns 1 to 101 by 1.

```
87778887778777877777778888888888888359988877788886369999988888888778889888877777358788877777887777777777
88788877877777777777888888888888886999877777878866778998888888877766888777777743987777777777877777777777
88888877777777777777788888888888886359887777787786667789888988873113543677777773598777788888877777777777
88888877777777777788877888888888883597777777887776677888998883111332256777774358778788888987777777777777
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87777899998878887777779AA98888988896115996666666666999961111222211297777458786666688877777777778896468
77777899998877777777789999888988999832595555663556655993122221111137777439788666698887777777778996668
777779999988777777777898888899889987765311139835555533631211111111147773587888765987877777777778986687
777779988877777777777888888998899877765311149659888763311211111111113773588877776588777777777777888787
777777888877777777777888686989989877776311146699887775112311121111377436887776889888777777777766888888
777777888877777777777888889988989897777662111679888778623632122134477435778876587866877777777778888699
77777888887777477777896888988888798777886311688987777866633344377777358788887668639777777777768888899
77787888874677777777898888888888888778888733999886677788323364426777735888878863588977887787777768887888
777778888636777777777888888888888987888886558963336778866444436877435888888788988867888888888778878888
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7788888888777787777788888899888999877777777783333353386211111676336688788987669A96333367768877888888888
78887777777777777777888888888878999777887777786236776366111111335566677888988669AA96643678788768888889888
7887888777777777777778878888889987778877877773577776361112333359999647668888896AA998666333686588888988 7
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8877777746777766555363333633333633643333322222356686599899877887744698644488886699988888988889998887777
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776633333233555999899999888888888888899998646743676676999986677699644688887449998568888887789987777778
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632259887776667666669999888889989988999886688669866597774464446999887644444444114665677666634 69AAA99998
321138888863596853359668888888899999889866877747633596444444446887774414444444446669999999965AAA999988
33236668873258883335863688888889999877776566664685563564446644447444444144444444465998889988 9AA9988877
633553488865666632565688888888999888874333447666555321344444444444441114444444444433667652599999788879
3238968777832223558339888888888999886776344444432252144144444414444444444444444444455555565688696358899
311587777865255535335988888888888835764441444423221144446864441144444444444444444465553656666889999998
656214777788865993556988888888888999667644411144344114444449988644464466444447776955986668866669999 99888
889647777786399963368888888886535999873344414444444311444469998888888888887766655559987666665559999 8786
98997788778658896335878888883333599886564444444444444444449A998888777888668636534599876656666699998 88899
359877777755588863566888888873333696599866444144444444411146A9899888778999663334666559878899878999888 88888
55598777788965888855569878885555676556666744444444444444148998998995699888653446966599776996469888888 87
```

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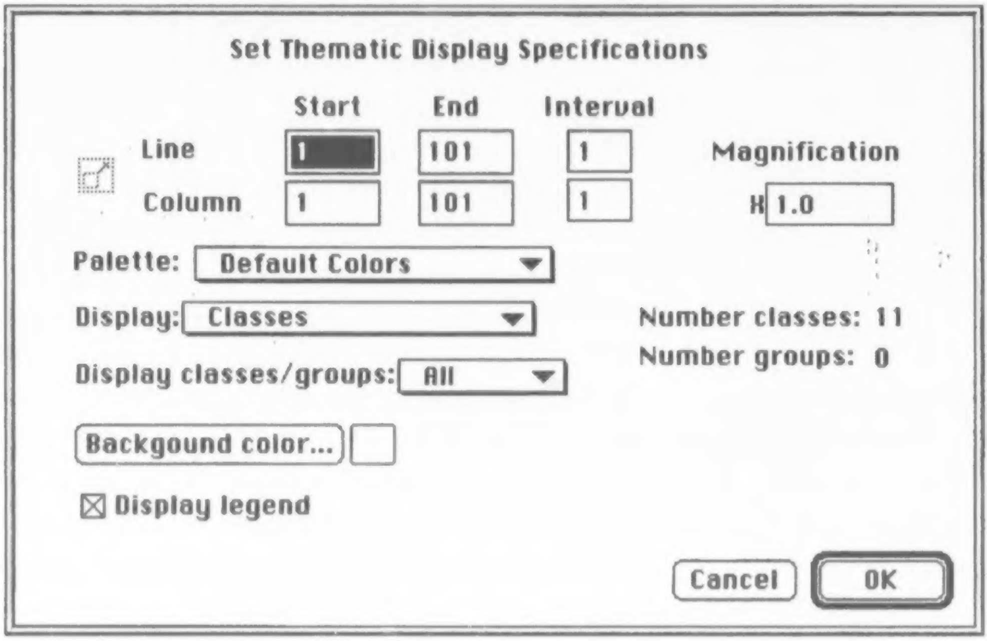
Also produced is a classification summary, shown below, which gives the number of pixels in each cluster, and the number of pixels that were not classified.

```
Classification summary
Cluster  1 classification size:   247
Cluster  2 classification size:   252
Cluster  3 classification size:   770
Cluster  4 classification size:   676
Cluster  5 classification size:   789
Cluster  6 classification size:  1277
Cluster  7 classification size:  1907
Cluster  8 classification size:  2703
Cluster  9 classification size:  1366
Cluster 10 classification size:   214
Number of pixels not classified = 0
```

In this case, remember, there are 0 unclassified pixels, because you set the **Classification threshold** to 100.

Examining the Clustered Image

- From the File menu, select **Open Image**.
- Select the **.Cluster** file name you used earlier, and click **Open**.
- The **Set Thematic Display Specifications** window opens, as shown below. You can experiment later with some of the other palettes in this menu, but for now accept the default settings and press **OK**.



Set Thematic Display Specifications

	Start	End	Interval
Line	1	101	1
Column	1	101	1

Magnification

X 1.0

Palette: Default Colors

Display: Classes

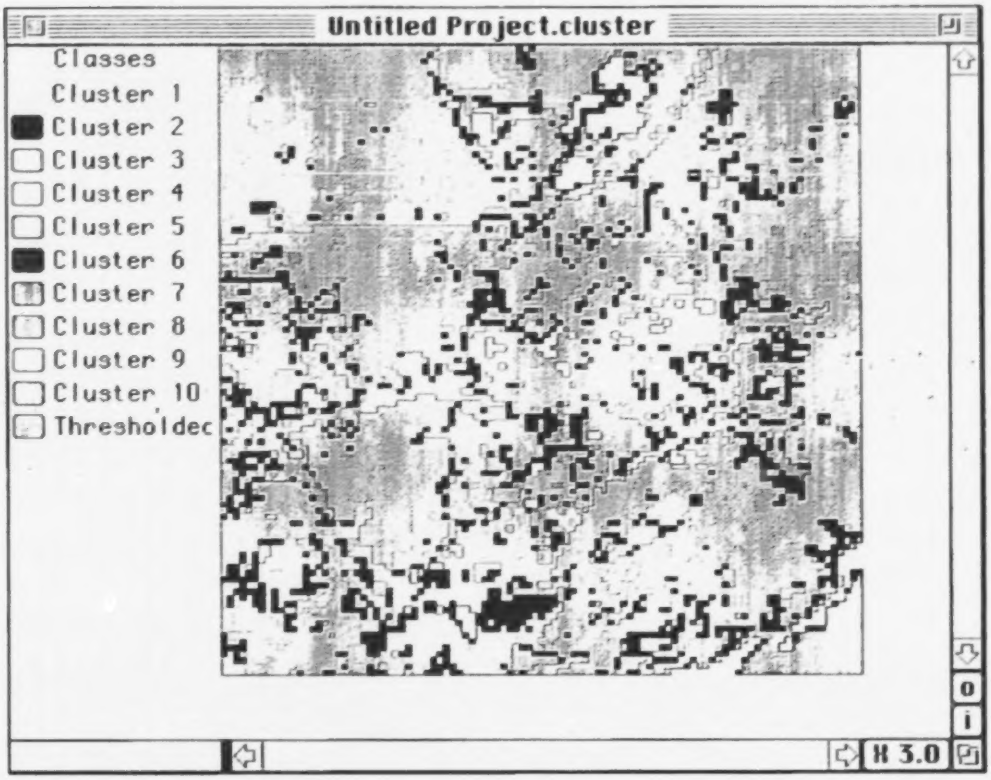
Display classes/groups: All

Number classes: 11

Number groups: 0

☒ Display legend

- Your clustered image opens, as shown below.


Untitled Project.cluster
Classes
Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cluster 6
Cluster 7
Cluster 8
Cluster 9
Cluster 10
Thresholdec
X 3.0
o
i

- Notice that there are 10 numbered classes, and the 11th "Thresholded" class. Each class is assigned a color by the system which has nothing whatsoever to do with what the cluster represents. The clusters are produced and arranged in order of descending level of brightness. That is, clusters near the top of the list represent surface materials that are "brighter' (have greater reflectance) than those near the bottom of the list.
- You may change any color by double-clicking on the color box in front of each cluster identification. You will get the standard Apple color selection window for your operating system. If you are not familiar with this color selection system, see your computer Users Guide.
- You may print the image from the **File** menu. When you do, the clustering key will be printed along with the image.
- You may use some of MultiSpec's regular tools with this Thematic Map. Such tools as: the **Zoom** feature, and **Show Selection Coordinates** function normally. The **New Selection Graph** feature will show a plot with only one piece of data. This map is no longer "multispectral." Each pixel no longer contains data for different LandSat bands, or channels. Each pixel contains only one value, which identifies its color.

- If you do a clustering with a larger number of classes, you may not be able to see them all in the "**Classes**" column. To scroll through this column:
  - Move your cursor into the column
  - Hold the mouse button down
  - Drag to either the top or bottom of the column.

The classes will scroll up and down.

  - It is sometimes difficult to tell which color in the **Classes** column matches colored areas in the image. To match classes to their image areas:
  - Place the cursor over any color box in the "Classes" column.
  - Hold down the shift key. The cursor changes to an "eye."
  - Depress the mouse button, and the areas in the image of that class will "blink," or turn to white.

- You and your students will probably want to prepare a thematic map from this clustered image in which you identify some of the clustered areas by their actual land cover. To do this, you may save the image as a **TIFF** file from the **File** menu. This process does not save the clustering key, only the image area will be saved. The TIFF file may then be brought into any one of a number of paint or draw programs to be "fancied up" as a thematic map.
- If you wish to have an image that contains the clustering key, and can also be moved into paint or draw programs you can capture the entire screen using Apple's "**Shift-Command-3**" feature. Hold down the Shift key, the Command key, and press "3." A "snapshot" of the screen is saved as a PICT file on your fixed drive and may be opened by any program that will handle PICT files. For PC computers, there are a number of programs that will accomplish the same screen "snapshot, and for Macintosh users there are several programs that do "screen captures" in a more flexible manner than the system's "Shift-Command-3" utility.

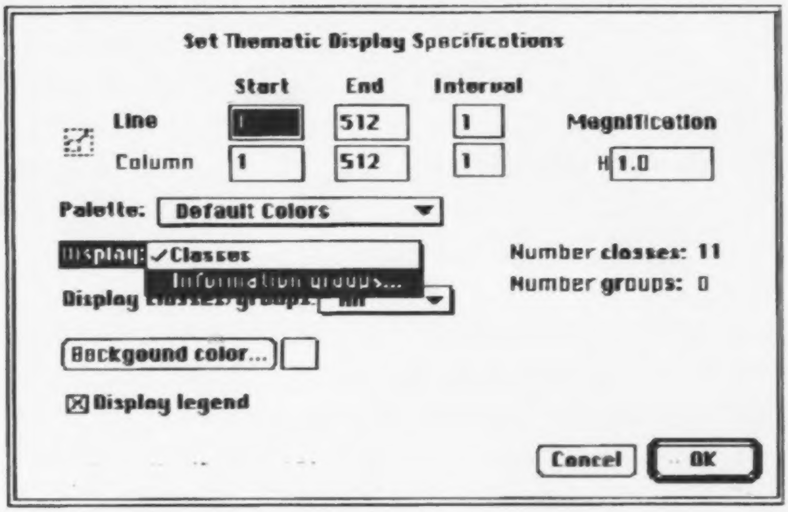
How Valid Is the Clustering Process?

It is necessary for you to be confident that this process of "unsupervised classification" actually yields clusters that are related to land cover types. To this end, included with this tutorial is a file named "**Beverly9subset.class**". This is the same image that you have clustered, only this image was prepared with a **supervised** classification by an individual very familiar with the land cover types in the area.

- In your clustered image, zoom in to 3X.

With your clustered image open, open the **Beverly9subset.class** image.

- From the **File** menu, select Open.
- Locate the **Beverly9subset.class** image, and **Open it.**
- When the **Set Thematic Display** window opens, as shown below, select **Information Groups** from the **Display** menu.



Set Thematic Display Specifications

Line: Start 1, End 512, Interval 1

Column: Start 1, End 512, Interval 1

Magnification: H 1.0

Palette: Default Colors

Display: ✓Classes

Display classes/groups: All

☒ Display legend

Number classes: 11

Number groups: 0

- Re-size and position each image so they are side-by-side on the screen.
- Compare the areas identified in the supervised classification to the clusters produced by the system in your unsupervised clustering.

You should see that the unsupervised clustering provides, at least in this case, a good indication of the locations of large areas of uniform land cover that could be investigated for verification studies.

How Many Clusters Do I Use?

Most regions the size of your 15 km x 15 km Primary GLOBE study site do not generally demonstrate a large number of different land covers. When you first perform a clustering on your 512 x 512 image, use the same values as you used in this tutorial. Examine the results in light of your knowledge of your own area. Do some field work and look at the areas your clustering suggests are fairly large and homogeneous. Compare your findings to the MUC classification scheme. Only if you feel that this clustering does not adequately represent the land covers in your area should you increase the number of clusters, and then 12 to 14 clusters should be sufficient to do the job.

Reporting the Data

In order to report your data, you must make some "sense" out of the clusters determined by this unsupervised process. You can then re-label the clusters as what type of land cover they represent. The process involves the following steps:

- Desk Verification
- Field Verification
- Renaming the Clusters
- Send in your completed map.

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Desk Verification

This process involves your use of local maps (topographic, land cover, soil, political, etc.), other local references (aerial photos, people, agencies, etc.) and the combined experiences of both you and your students to identify some of the clusters produced by MultiSpec. Use whatever resources you can to identify them. Remember that your identifications should correspond to the level IV of the **MUC** (Modified Unesco Classification) scheme.

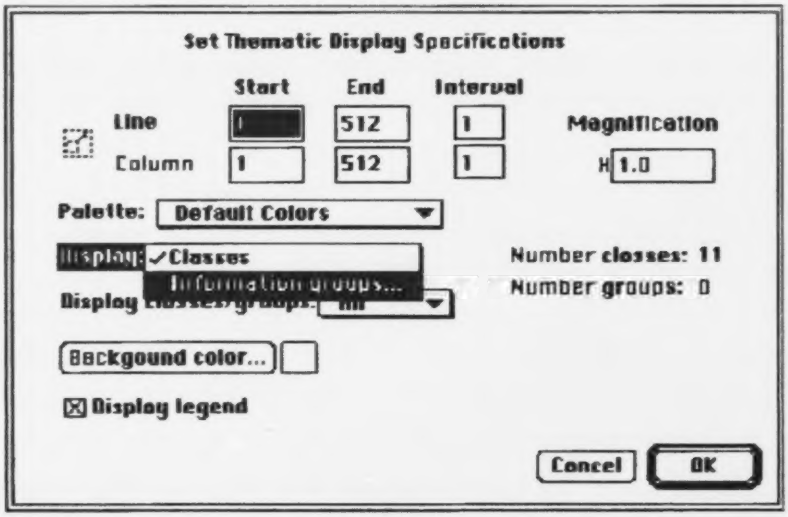
Field Verification

If there are clusters that you cannot identify "from the desk," you will have to go out into the field to determine what they are. If a formal "field trip" is not possible, in all probability someone lives near to or drives by that area and can do the identification.

Renaming the Clusters

Your unsupervised clustering produced clusters identified only by a number, and arranged in order of decreasing brightness. You will now change the titles of these clusters to the **MUC** classification codes that you determined from your verifications.

- Launch **MultiSpec**.
- From the **File** Menu, select **Open** and select your .Cluster project.
- When the **Set Thematic Display** window opens, as shown below, select **Information Groups** from the **Display** menu.



Set Thematic Display Specifications

	Start	End	Interval
Line	1	512	1
Column	1	512	1

Magnification H 1.0

Palette: Default Colors

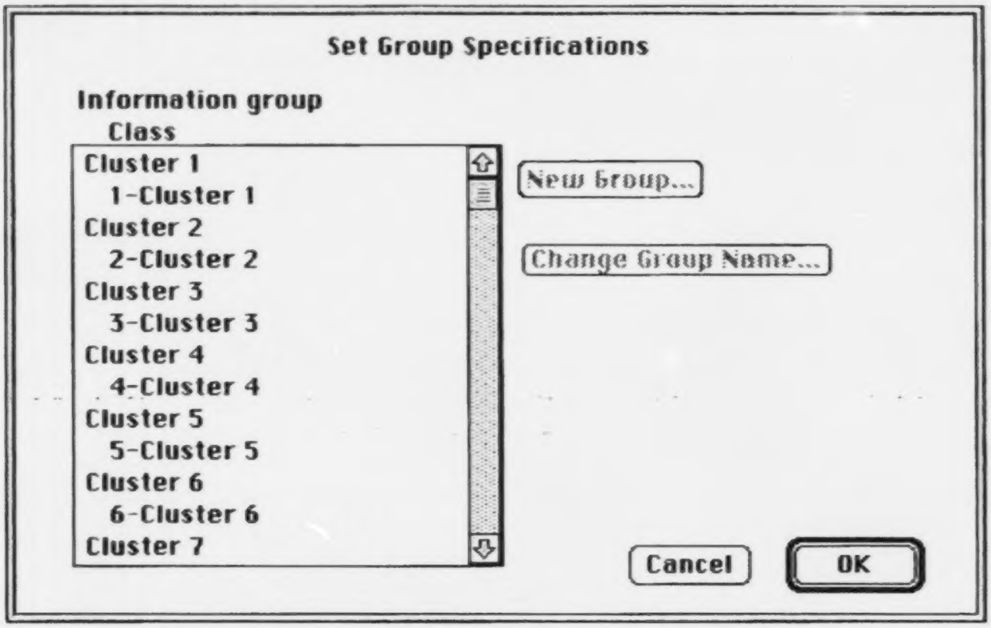
Display: ✓Classes

Number classes: 11

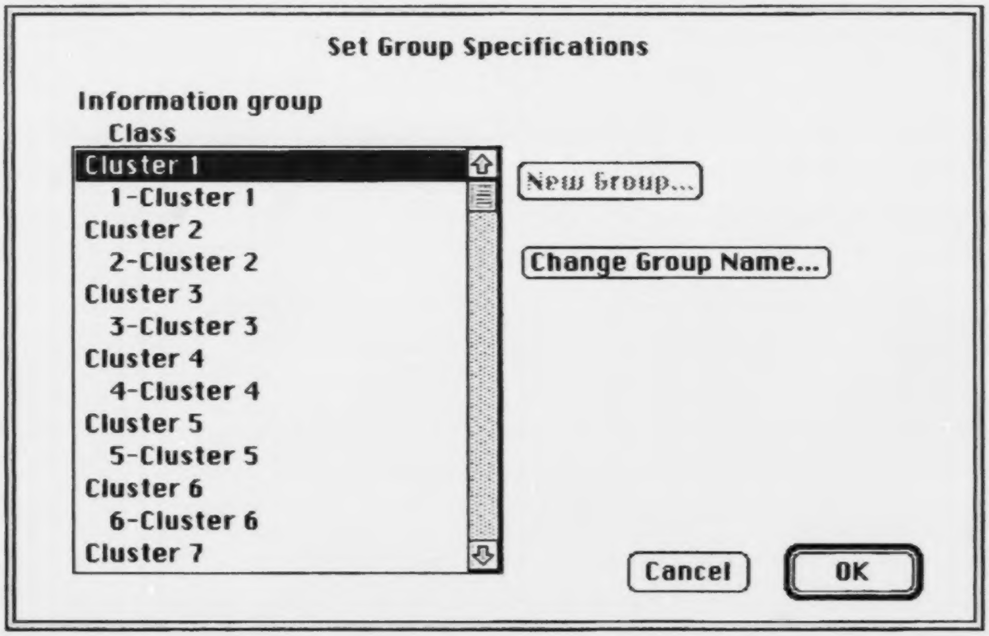
Number groups: 0

☒ Display legend

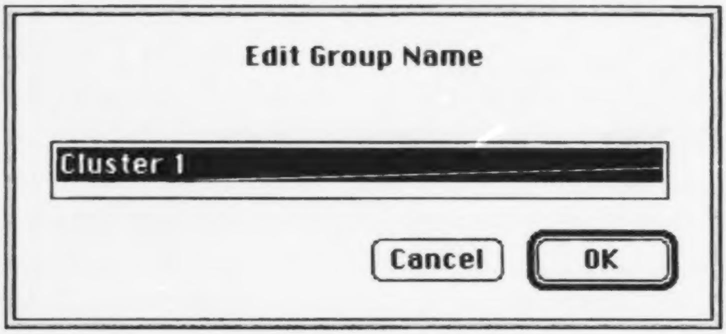
- The **Set Group Specifications** window opens, as shown below, with the "**New Group**" and "**Change Group Name**" buttons "dimmed."


Set Group Specifications
Information group
Class
Cluster 1
1-Cluster 1
Cluster 2
2-Cluster 2
Cluster 3
3-Cluster 3
Cluster 4
4-Cluster 4
Cluster 5
5-Cluster 5
Cluster 6
6-Cluster 6
Cluster 7
New Group...
Change Group Name...
Cancel
OK

- Click on "**Cluster 1**," and the dimmed "**Change Group Name**" button will darken, as shown


Set Group Specifications
Information group
Class
Cluster 1
1-Cluster 1
Cluster 2
2-Cluster 2
Cluster 3
3-Cluster 3
Cluster 4
4-Cluster 4
Cluster 5
5-Cluster 5
Cluster 6
6-Cluster 6
Cluster 7
New Group...
Change Group Name...
Cancel
OK

- Click on the **Change Group Name** button, and the **Edit Group Name** window opens, as shown below.



- Now enter, for Cluster 1, the proper **MUC Level IV designation** for the land cover represented by that cluster. Since many of the **names** of land cover types at this level are quite long, **use the MUC numerical designation** for each land cover type.
- **Repeat this process** for each of the other clusters in your map.
- You can change the colors of each of your named clusters to whatever color scheme you wish. (see above) When your results are sent to "Globe Central," a standard color code will be applied to it.

You have now produced a Land Use Thematic map of your 15 km x 15 km primary GLOBE Study Site.

A Note About Expectations, and a Caveat

When you proceed to the classification of your own 512 x 512 image, you will find the appearance of your clustered image probably considerably different than this demonstration. Major reasons will be:

a. This sub-set image does not contain as many land cover types as would be found in a full-sized 512 x 512 image.

b. The nature, abundance and distribution of land cover types in your image will certainly differ from those in the Beverly, Massachusetts area.

As you cluster your own image, you will find that specifying 10 clusters does not discriminate between standing bodies of water, except perhaps between fresh and salt water. In other words, lakes, ponds, rivers, etc. will probably all be clustered into the same group, unless there are significant surface properties that might change their reflectance (i.e., significant algal growth on the surface of a farm pond.)

Submitting your results:

Once you have an unsupervised classification (clustering) that seems to adequately represent your 15 km x 15 km GLOBE Study Site, your results will be submitted to the GLOBE Student Data Archive and made available for use in ongoing and future studies.

Specific directions for data submission are as follows:

- Make a copy of your clustered Thematic image onto a high-density floppy disk and clearly label it with your school name, your name, and "clustered image."
- Using your favorite word processor, prepare a file with the following metadata:

  Your School Name

  Your Name

  School Address

  Date your image was acquired (if available)

  Some information about yourself, your students, and some of your experiences in doing your clustering.
- From your word processors options, save this data as a text file and place it on the same disk with your Thematic Image.
- Carefully package these disks and send them to the address given in the *Implementation Guide* (optional).

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printed with soy ink

GPS Investigation

GLOBE DATABASE

A GLOBE™ Learning Investigation

GPS Investigation at a Glance

Protocol

Onetime Only Measurements:

Time of initial recording and averaged latitude, longitude, and elevation for the following Study Sites:

Atmosphere, Hydrology, Land Cover, Biology, Soil Characterization, Soil Moisture, and your school which is the center of your GLOBE Study Site.

Suggested Sequence of GPS Investigation

Reserve a GPS receiver from GLOBE as soon as possible. Details can be found in the *GPS Protocol* section, under *How to Perform Your GPS Investigation.*

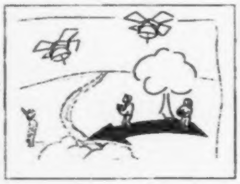
Read *Welcome to the GPS Investigation.*

Copy and distribute the scientist's letter and interview to your students.

Read the Protocol to learn precisely what is measured and how.

Prior to the GPS receiver arriving, determine the location of each of the GLOBE subsites, using Landsat imagery, other hardcopy resources (maps, atlases, etc.) and field observations.

When you receive the GPS receiver, have the students conduct some test measurements near your school, following the GPS measurement procedures found in the Protocol section. When you and your students are comfortable with the operation of the receiver go to your GLOBE study sites and, following the Protocols, take the position measurements at each site. Report your results back to GLOBE as soon as possible upon completing the measurements and calculations.



If one or more of your sites are obscured by tree canopy, conduct the GPS Activity *Offset GPS Measurements* to determine your site's position. Other than the protocol this is the only activity for which the GPS receiver is necessary.

If your students are experiencing difficulties with performing the measurements or are interested in further activities related to global positioning systems, refer to and conduct one or more of accompanying activities (*Relative and Absolute Directions, Working with Angles,* and *What is the Right Answer?)*

Return the GPS receiver to GLOBE as soon as possible. Again, the instructions can be found in the *GPS Protocol* section, under *How to Perform Your GPS Investigation*. Good luck and have fun!

Special Notes

The GPS receivers are lent by and must be returned to GLOBE or a GPS receiver can be obtained locally.

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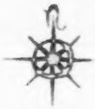

Welcome to the GPS Investigation

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Offset Data Work Sheet Appendix-3
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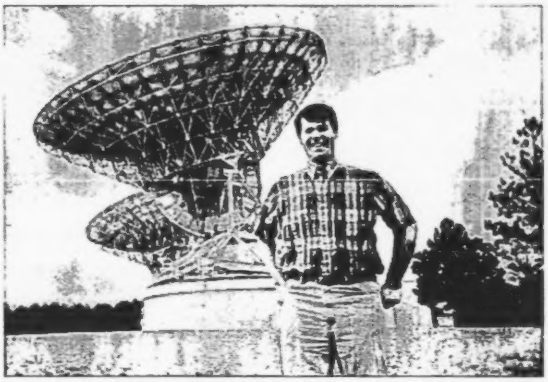
Scientist's Letter to Students

Duplicate and distribute to students.



Dear GLOBE Students,

We now are living at the edge of the resources available on our planet, and we need to be good stewards of the environment God gave to us. The GLOBE Program offers you the opportunity to participate in our learning more about the world around us.

It feels good to be interested in understanding our environment, but we can do more than just feel good. When we make scientific measurements, we can attach numbers to different issues that allow us to compare issues objectively. When we do this, we can claim to be making informed decisions about how we wish to direct ourselves.

I am the GLOBE Program scientist who is helping you to use the satellite navigation technique called the Global Positioning System. You will be using a hand-held device that receives timing signals from satellites 20,200 kilometers in space to measure your latitude and longitude with sufficient accuracy that you can pick out your school or home in a satellite photograph. When you submit your location measurement, you will help participating GLOBE scientists and students geographically relate all of your GLOBE measurements.

Please attempt to maintain the integrity of your data when you make your GLOBE measurements and data submissions. If someone says that they are not interested in science or quality, ask them again when someone they care about gets sick and becomes well by using an antibiotic, or even the next time they flush a toilet. This is your opportunity to put to use your science, math, and geography skills to contribute to an effort to better understand how our world works.

A lot of folks are working with this program, but we are depending on you because you are the expert on your home. I look forward to working with you and seeing the fruits of our labors.

Whit Smith

Whit Smith, Ph.D.
Senior Research Engineer
School of Electrical Engineering
Georgia Tech
Atlanta, Georgia 30332
USA

Meet Dr . Whit Smith

Duplicate and distribute to students.

Dr. Smith is a Research Engineer at Georgia Tech in Atlanta, Georgia, USA.

GLOBE *What kind of data do you need and why do you need it?*

Dr. Smith: I need your latitude, longitude and elevation above sea level so we can locate you in satellite images. The other scientists want to know exactly where you are in these pictures so that they can compare measurements made in your area to measurements in other locations.

GLOBE *Why not just refer to maps?*

Dr. Smith: We want to locate you in satellite images. The size of each picture element or pixel on a Landsat satellite image is 30 meters on a side. When using a topographical map, it is difficult to get down to the nearest 30 meters.

GLOBE *Will the Global Positioning System ever replace the hand-held compass?*

Dr. Smith: No, GPS doesn't tell direction. It tells you where you are. Compasses tell direction, but not where you are. So you need both.

GLOBE *Have students used GPS technology before?*

Dr. Smith: Yes, many have used them for other projects such as Boy Scouts or hiking applications. Anybody who's navigated a boat or an airplane may have used this.

GLOBE *Tell us about yourself. Where did you grow up?*

Dr. Smith: I was born in a little town in eastern North Carolina called Goldsboro and attended grade school and high school there.

GLOBE *Do you have a family and children?*

Dr. Smith: No, nor any pets. I have lots of students.

GLOBE *When did you become interested in science?*

Dr. Smith: I've always been interested in science and technology, probably because science is searching for truth. I've always been interested in electrical, mechanical type things. When I went to Electrical Engineering school, I found radio and communications most interesting.

GLOBE *If there were anything you could know about your science, what would that be?*

Dr. Smith: I would like to better understand electromagnetics – how electric and magnetic fields interact – and probability. Those were always hard subjects for me. Even people who make 'A's in those things may not really understand them.

GLOBE *What is it about electricity that you want to know?*

Dr. Smith: I'd like the deepest possible understanding of how electricity works. We know it works but don't really know how.

GLOBE *Is that knowable?*

Dr. Smith: I doubt it. There are infinities among infinities of things to understand, and if you can understand just a thimbleful, you're doing well.

GLOBE *You're a Research Engineer: correlate that with a scientist.*

Dr. Smith: Force equals mass times acceleration. That works, but it took a long time for somebody to actually recognize it. Engineers apply those laws and make something out of them. The scientific process—which engineers do, too – is to hypothesize something and then test it to see if it's true. Once you find the general truth, then you can use it. Engineers use those truths to make useful things.

GLOBE *So you're applying that knowledge to create new technologies?*

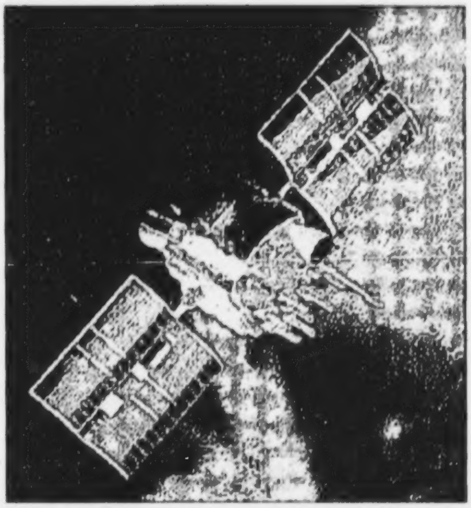
Dr. Smith: I both search for it and apply it. When I'm searching for it, I'm a scientist; when I'm applying it, I'm an engineer.

GLOBE *Is there a greatest challenge that sticks in your mind?*

Dr. Smith: I got handed a pair of gigantic satellite antennas three years ago that are ten stories tall and a hundred feet in diameter. They're larger than most buildings. They belonged to AT&T.

GLOBE *These were handed to you?*

Dr. Smith: Yes, they're sitting out in a corn field about 65 miles south of Atlanta. Georgia Tech acquired them. I was told, "Go do something with them?" And I said, "Well, what?" They said, "Something." I said, "Well, what?" They said, "Something!" And I said, "Okay." So I recruited students to see if we could hook up some radio equipment and hear noise from stars or talk to satellites. Two years later, we could crank those antennas toward Jupiter when the comet Shomaker-Levy hit in the summer of 1994. We measured the radio noise from Jupiter that we hope to correlate with the impact of the comet. So the students and I were able to build a radio-astronomy and satellite-communication facility out of junk. That was a big challenge.



GLOBE *What is your day like?*

Dr. Smith: I don't have a typical day. On Saturdays, I go with students to my antenna facility. One student may be installing a motor to make the antenna turn, and another may be working on interfacing that motor to a computer.

GLOBE *When you say a motor –*

Dr. Smith: I mean an electric motor the size of a trash can that when geared way down can turn a ten-story building. These are giant satellite dishes. I can point them up and down and right and left. That's Saturday. During the week I might be teaching classes and meeting with students to discuss their issues. I have lots of meetings for GLOBE and other programs. I spend time writing computer programs and reports, and doing analyses.

GLOBE: Do you have a lab?

Dr. Smith: The antenna facility is the lab. We have labs based on campus where we design, build, and test the equipment that we're going to install at this facility, but the facility is really the lab.

GLOBE: Who were your heroes when you were growing up?

Dr. Smith: Astronauts.

GLOBE: Do you have any heroes today?

Dr. Smith: Probably Biblical characters who showed some strength of faith.

GLOBE: Faith is important in your work?

Dr. Smith: Yes. It's important in everything everybody does. Stepping on the floor and hoping that it will hold you up requires some faith.

GLOBE: What are the rewards of science?

Dr. Smith: If you can see something neat being done, that's nice, but in my case, I'm building instrumentation to help somebody else see something. What are the rewards of the data from GLOBE? Well, mainly seeing the bright, smiling faces of the students is to me the neatest part.

GLOBE: How will students benefit from their involvement in GLOBE?

Dr. Smith: Realizing they have some input on the way the world works, both in terms of nature and their ability to touch technology and science and influence it. I think most students see science and technology as a mysterious black box that they don't understand. Yes, there are mysteries out there, but we have been given the gifts that allow us to think about what's going on around us, and to observe and to make characterizations.

GLOBE: Going into the 21st century, do you think that students will need a basic understanding of science and technologies?

Dr. Smith: Yes. There are folks who are scared by science and technology, and folks who are willing to embrace it. People who are not willing to work with science and technology could become second-class citizens. If they take an attitude of 'I don't know how to program a VCR and I'm proud of it,' they will have a lot fewer resources than others. You can see that happening now. People who are willing to work with the computers and those who are not.

GLOBE: What would you tell a student about entering your field?

Dr. Smith: Science and engineering are fields which require a substantial commitment of time and effort. People who enter these professions and who experience the enjoyment of discovery will be satisfied with their careers.

GLOBE: *Do you have any advice for students who are interested in pursuing science?*

Dr. Smith: Try to find grown-ups who are willing to be mentors. Talk to them, interact with them and try to build something.

GLOBE: *Did you have mentors as a student?*

Dr. Smith: An older engineer was very, very helpful to me. I wish I had gone into Amateur Radio at an earlier age because then I would have met a community of people who knew about science and technology.

GLOBE: *So when you were a student, you had this feeling that this was the direction for you?*

Dr. Smith: Every generation has its issues. During World War II, it was totalitarianism. Then it was fear of nuclear war. In the U.S., in the 1960's, young people were questioning and rebelling against institutional authority. With the 1970's and people began focusing on environmental issues. If people are concerned about other environmental issues, then a mechanism for empowerment would be to learn about the scientific consequences of environmental issues. In science and engineering you learn how to put numbers on things or events, so you can make a measurement and know quantitatively and objectively what is going on. For instance, you may advocate solar power, but may not know what you're talking about. But if you're an engineer or scientist, and know that one kilowatt of sunlight falls on every square meter, and you know that one square meter of solar cells costs so many dollars, and you know that one square meter of solar cells is going to be 10 percent efficient so you can get 100 watts out of every square meter in electricity, you now know how much electricity you can make out of sunlight. You can put numbers on it, figure out how much it costs, and make intelligent statements about some mechanism that influences your world and your biosphere.

GLOBE: *What today is the frontier of your field?*

Dr. Smith: The two biggest areas for Electrical Engineering are personal communications, such as pocket pagers and cellular telephones, and optical devices like fiber optics and computers that are operated from light. You can put an incredible amount of data over a single fiber of glass thinner than a hair.

GLOBE: *Are there limits to what science can discover?*

Dr. Smith: A lot of people see science as an attempt to steal mysteries from God. Scientists won't ever know everything, and there is nothing wrong with leaving a little mystery out there. There are an infinite number of opportunities to do something with what little we know. I believe that we are stewards of this world and it is not unreasonable for us, in fact, it is reasonable, to try to understand the world and treat it well. And that's where the students can help. Their data will help us learn how our world works, so we can make those intelligent decisions.

Introduction

The Big Picture

Overview

A Global Positioning System (GPS) receiver is a hand-held device that receives data directly from overhead satellites. With a GPS receiver, students can determine their location, as measured in latitude and longitude, almost anywhere in the world to an accuracy within 100 meters. If they average several measurements, typically they can determine their location to within 30 meters, which is the size of a single Landsat image pixel. Thus, students can determine the location of their 30-by-30-meter GLOBE study sites with sufficient accuracy to identify their unique pixel in Landsat images.

Yes, students will use satellite data. Although it was originally designed for military uses, GPS is now used primarily in civilian applications. As a part of GLOBE, we want your students to determine the latitude and longitude of their school and study-sites. These data will locate the sites of their biosphere measurements and will be used by scientists and students worldwide. If you do not have access to a GPS receiver, then the GLOBE Program can assist you in borrowing one. If you are at a U.S. GLOBE school, then the GLOBE Program can loan your school a hand-held GPS receiver. If you are at a non-U.S. GLOBE school, then you can borrow a GPS receiver from your country coordinator. See GPS Investigation Part II for details.

Satellites

Many types of spacecraft exist. Unmanned scientific spacecraft such as Magellan, Viking, and Galileo have been sent to Venus, Mars, and Jupiter to perform physical measurements and relay their data back to Earth. Voyager 1 and 2 continued out of our solar system in the 1980's after observing several of the outer planets. In 1995, the Galileo spacecraft dropped a probe into Jupiter's atmosphere. While it passed through the atmosphere, withstanding intense atmospheric pressure and temperature, this probe radioed its sensor information back to Galileo, which in turn relayed it back to Earth.

Manned spacecraft such as the Apollo series, Space Shuttles, and the Mir Space Station have people onboard. Unlike unmanned spacecraft, these vehicles need to provide an atmosphere, temperature control, food, and the other facilities necessary to support human life. For these and safety reasons, manned spacecraft typically are much more expensive and complex than unmanned spacecraft. However, the presence of people in space provides an opportunity for our human ingenuity to handle unplanned events in addition to allowing us to experience and enjoy being in space.

A spacecraft in orbit around a larger body is called a satellite. When the Galileo spacecraft reached Jupiter and slowed down to enter into an orbit around the planet, it became a satellite of Jupiter. When we launch a satellite into orbit around Earth, it becomes an artificial satellite of Earth just as our moon is a natural satellite of Earth. These artificial satellites in Earth orbit perform a variety of tasks including: long-distance telephone, television, and data communication, weather and natural-resource observations, military surveillance, and basic science measurements.

Our moon is 384,500 km from Earth, and it takes about one month to complete one orbit. Because of fuel limitations or a desire to perform close observations, Space Shuttles and some observation satellites are only a few hundred kilometers above Earth. These "Low-Earth-Orbit" satellites take a minimum of 90 minutes to complete one orbit. Communications satellites are in orbits 35,792 km above Earth. At this altitude, these satellites take exactly one day to circle Earth. This special orbit is called "Geosynchronous Orbit." A satellite in geosynchronous orbit always appears to be at the same place in the sky to a terrestrial observer. Thus, an antenna pointed at a geosynchronous satellite need not move.

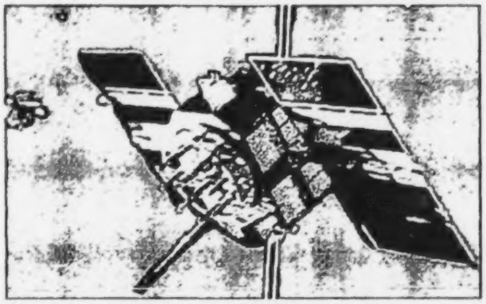


Figure GPS-I-1: A Global Positioning System Satellite

Compare this to a Space Shuttle which may pass from horizon to horizon in minutes or our moon which may take a month to move across the sky.

GPS Satellites

The Global Positioning System consists of a series of satellites, their ground control stations, and users with GPS receivers. See Figure GPS-I-1. These satellites are unmanned. They are launched by expendable rockets that place them into orbit. There are 24 GPS satellites in orbits 20,200 km above Earth's surface. At this altitude, the satellites take about 12 hours to complete one orbit. The satellites are spaced in their orbits so that at least four are always in view of a terrestrial observer at any point on Earth.

Powered by solar cells, the GPS satellites contain a controlling computer and communicate with the Earth via radio. Each satellite contains four atomic clocks, which are so accurate that they differ by only one second in 150,000 years. These clocks generate the time signals that are transmitted from each satellite. Software executed by a computer in a GPS receiver locks onto the timing signals from at least four satellites to determine the receiver's latitude, longitude and elevation. The receiver can be on the ground, at sea, in the air, or in space.

As a testimony to its increasing popularity and utility, the Global Positioning System was the cover story for the February 1996 issue of *Scientific American* magazine (volume 274, Number 2, pages 44-50).

Preparing for the Field

Perhaps the most complicated equipment that students use in GLOBE are the GPS receivers. Some of the activities in this investigation will use the GPS receiver, which teachers and their schools can borrow from GLOBE for a week. The best way to begin using the instrumentation is to have a solid knowledge of science and mathematics and a good sense of science-process skills.

Use the GPS investigation to integrate GLOBE science with other disciplines like social studies (from the history of exploration to the dynamic differences and similarities of different cultures and peoples), mathematics, and the visual arts with emphasis placed on observational and recording skills.

Student Learning Goals

Science Concepts

The conceptual questions that frame the GPS investigation are basic to our very nature:

1. "Where am I?," and
2. "How do I know?"

A systematic approach to these questions will address:

1. *Relative to absolute geographic descriptions of a position* - from a relative description ("I am at school"), through less relative directions (North, South, East, West), to an absolute reference frame (Latitude and Longitude).
2. *Earth and its satellites* - artificial, natural, and the GPS navigation role.
3. *Data quality and instrumentation* - how and why we use instrumentation and how we might "trust" the data.
4. *Mathematics* - from measuring to geometry and trigonometry.

Science Process Skills

In the GPS investigation, students will be:

Observing things critically
Identifying patterns to determine similarities and differences in observations
Asking questions based on their observations
Expressing and *recording* observations systematically
Manipulating, analyzing, and *integrating* observations and data
Drawing conclusions based on the observations and data
Communicating observations, questions, and thoughts

Student Assessment

The GLOBE investigation provides interesting opportunities for students to become engaged in science and mathematics. Your tasks as a teacher include knowing how your students are changing in the process—how they are growing—more than how they are performing some protocol. While performance is obviously important, given the general concern for the safety of the students, the expense of some of the instruments, and the need for accurate data, the real educational key is the development of systematic and critical attitudes toward what are listed above as *Science Process Skills*. Specifically, you can evaluate the students by comparing their performance against a criteria based on the above list.

Evaluate the students as follows:

1. *Observations* – Can students pick out and list details? Can they describe what they observe?
2. *Comparing and contrasting* – Can students find differences and similarities between what they are observing now and what they observed before? How do the present data relate to past experiences? That is, where have they seen similar things? Can they explain differences, for example, in latitude and longitude, in directions or in mathematical approaches to problems?
3. *Questioning* – Can students ask questions of one another, of the teacher, or of others in the community, including the scientific community? Have your students record their questions. Encourage them on tests to write questions that they think of extemporaneously.
4. *Recording* – Perhaps the easiest way to evaluate students on skills and concepts is to see how they record in the field (during the activity), as well as after the activity. Evaluate how they record thoughts and insights, even questions, both during and after the activity, through their GLOBE Science Notebooks, essays and reports (both written and oral). The young student can record with pictures. Discussions about the pictures will provide insights into the thought processes of the student. Also, electronic recordings will be helpful in evaluation. These can range from audio and video for all levels of students, to copies of GLOBEMail messages, and computer graphing.
5. *Conceptual and critical thinking* – Will students choose to step outside of the presented framework of questions and recording tasks to generate their own models, pose their own problems, and solve these problems? While mathematical problems may be the easier for you to devise for students, you can always use "what if" or "why" questions. Activities like the modeling of the satellites or the offset GPS measurements encourage critical thinking in students. Observing and evaluating the students in the process, as to their focus, their effectiveness, and their perseverance will be helpful. Also, can they evaluate the situation for you at any given time?
6. *Communicating* – More than any other skill, this is probably the most critical for a student's future success and the most difficult to evaluate. Evaluation of

language skills is crucial. Mathematical communication skills and interpersonal relations during the activities are vitally important at all ages. While difficult, peer evaluation techniques are particularly valuable here. Can students evaluate each other?

Your use of quality educational-assessment processes can encourage students and make a significant difference in their development.

Protocols

Students should learn the basics of GPS.

Obtain a GPS receiver from GLOBE or another source.

Practice making GPS measurements near the school.

Make the GPS measurements at the sites specified.

Submit your GPS data to GLOBE.

Return the GPS receiver.

How to Perform Your GPS Investigation

Preparation

Sites for the Investigation

Students must determine the latitude, longitude, and elevation of their school, which is the center of their GLOBE Study Site, of their Atmosphere, Biology, Hydrology, and Soil Moisture Study Sites, and of each Land Cover and Soil Characterization Sample Site. The GLOBE Program makes a hand-held Global Positioning System satellite receiver available to you. See Figure GPS-P-1. Before borrowing a receiver you should determine locations for those GLOBE sample or study sites where the students will be making measurements during the coming year. Generally, it is not possible to borrow a GPS receiver from GLOBE more than once per school year.

Places for GPS Measurements

Site	GPS measurement location
School	Main entrance
Atmosphere Study Site	Instrument enclosure and rain gauge location
Hydrology Study Site	Surface water-sampling location
Biology Study Site	Center of 30 m x 30 m site of repeated biometry measurements
Land Cover Sample Site	Center of each 90 m x 90 m site of land cover assessment
Soil Characterization Sample Site	Soil profile location
Soil Moisture Study Site	Center of the star or middle of the transect

The Atmosphere and Soil Moisture Study Sites should provide clear views of the sky and thus good satellite reception, but the Hydrology and Biology Study Sites may offer poor GPS reception due to heavy canopy cover. The school location is to be determined at the front or main entrance to the school, and usually the building will block satellite reception to some extent. To resolve this problem, refer to Offset GPS Protocol.

Frequency

The latitude, longitude and elevation of each study or sample site as determined using GPS technology needs to be performed and submitted only once.

Instrumentation for the GPS Measurement

The GLOBE Program owns GPS receivers which are maintained by the University Navstar Consortium (UNAVCO). To borrow a GPS receiver, U.S. schools should direct their requests to UNAVCO. Country coordinators may request to borrow GPS receivers from UNAVCO for use by their non-U.S. partner GLOBE schools. Requests should be sent to:

Web:	http://www.unavco.ucar.edu/
e-mail:	globe@unavco.ucar.edu
phone:	(303) 497-8000
fax:	(303) 449-7857
address:	UNAVCO/UCAR PO Box 3000 Boulder, CO 80307-3000

Please return borrowed receivers to:

UNAVCO/UCAR
3340 Mitchell Lane, Suite 393
Boulder, CO 80301

You might have access to other GPS receivers through local outdoor enthusiasts or surveyors, but be sure they meet the specifications stipulated in the Toolkit. Some schools have even purchased their own GPS receivers, and the prices of these devices are decreasing. Because of our limited number of receivers and our desire to have you use available instruments, data received from other brands of GPS receivers are acceptable. In any case, identify your receiver when you enter your GPS position data into the Web Data Entry Sheets.

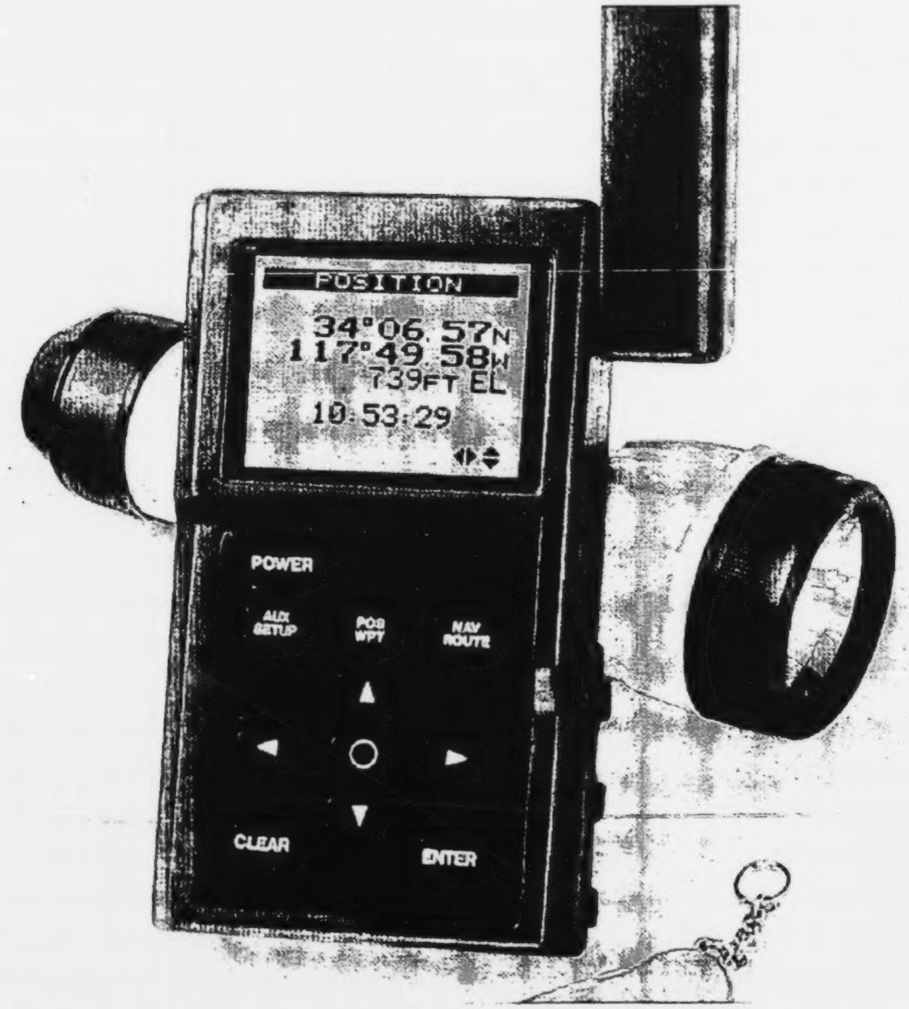


Figure GPS-P-1: An example of a hand-held GPS receiver used for illustration purposes. GLOBE does not recommend specific brands or models.

The variation of GPS location service used by the GLOBE Program is specified to provide an accuracy of 100 meters by the United States government GPS service. See the list of tutorial GPS Internet sites for more details. UNAVCO learned that averaging 15 measurements taken at one minute intervals with the GPS receiver typically can reduce this error to less than 30 meters.

The engineers who built and programmed your GPS receiver determine your location by inferring the distances to four or more satellites by knowing the locations of the satellites and by measuring the differences, in billionths of a second, in timing signals broadcast from these satellites. Many of the details of how the GPS system determines your location are spread throughout the learning activities.

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Basic GPS Measurement Protocol

Purpose

To determine the latitude, longitude, and elevation of the main entrance or front door of your school and of the GLOBE Study and Sample Sites whenever satellite reception is not blocked by buildings or trees

Overview

The GPS receiver will be used to measure the latitude, longitude and elevation.

Time

15 minutes to 60 minutes per study site

Level

All

Frequency

Once

Key Concepts

Latitude and longitude mapping

Skills

Reading maps

Using the GPS receiver

Using latitude and longitude in mapping

Materials and Tools

One GPS receiver

A copy of the GPS Protocol Work Sheet

A pen or pencil

Preparation

Select the sites and bring the GPS unit and data recording sheets to field sites.

Prerequisites

None

Procedure

Each measurement should take about 25 minutes (average) after arriving at the measurement site.

Before the Measurement

Decide where you wish to perform your measurements. Be aware that obstructions such as tree cover may reduce the satellite signal quality.

During the Measurement

1. At least two students should take the work sheet and a GPS receiver to your measurement site. One student will operate the instrument while another records the data.
2. Press the ON/OFF button once to turn on the receiver. Rotate the antenna so that it is vertical. After an introduction message, the receiver displays previous latitude, longitude, and elevation values while it locks onto the satellite timing signals. You may hold or set down the receiver, however, do not obscure the antenna's view of the sky. See Figure GPS-P-2 for a diagram of the GPS receiver.
3. Wait for the receiver to indicate that at least four satellites have been acquired and that a good measurement is available (which means that the "2-D" and status icons are removed from the screen). See Figure GPS-P-3 for a diagram of the GPS receiver status icons. Please note that the display shown in Figure GPS-P-3 is representative of one manufacturer's device; others may be different.
4. At one minute intervals and without moving the receiver more than one meter, make 15 recordings on a copy of the Site Location Data Work Sheet of all digits and symbols for the following displayed values:

   a) Latitude c) Time e) Status Icons

   b) Longitude d) Elevation.
5. Turn off the receiver.

After the Measurement

6. Average all 15 latitudes, longitudes, and elevations.

The GPS Learning Activity *Working with Angles* shows how to average your angle measurements. In addition, the GPS data entry web page points to a page which can perform the averaging arithmetic for you.

7. Confirm for yourself that your results make sense.

You should be able to get a rough estimate of your latitude and longitude by looking at a globe or local map. Although it is unlikely that the receiver would display any errors (and thus be broken), if you become convinced that this is the case, contact UNAVCO to exchange receivers. We want you to be able to make these measurements easily and efficiently and do not wish for faulty instrumentation to inhibit you.

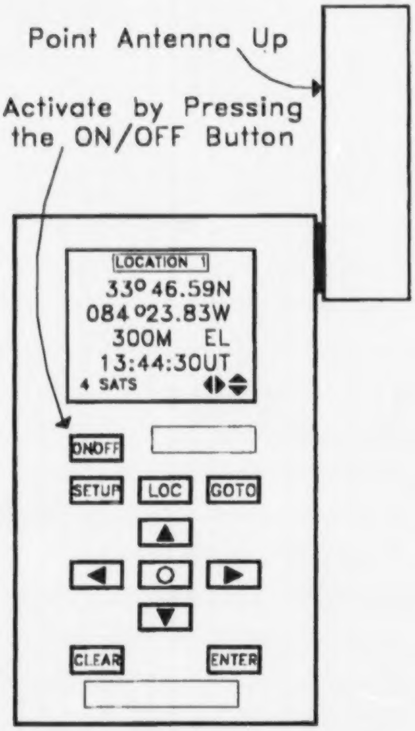

Figure GPS-P-2: Diagram of one example of a GPS Receiver

8. Copy and submit all GPS readings as your site location to the GLOBE Student Data Archive.

Follow this protocol at each site. Directions are specific to the GPS receivers presently being loaned by GLOBE. Please note that other GPS receivers may have different instructions. As local times vary in different time zones, UNAVCO receivers come with their time display set to Universal Time (UT) which is the same as Greenwich Mean Time or the time at Earth's 0° longitude. Regardless of the receiver used, we suggest that you look through the manufacturer's user manual to learn about features or solutions to problems not covered here.

If you are using another receiver, adapt as best you can to these directions, but be consistent. A receiver other than one provided by GLOBE through UNAVCO should have the capability and be set to:

Express latitude and longitude in whole degrees, minutes and decimal minutes to the nearest 0.01 minutes,
Display time on screen in units of UT hours, minutes, and seconds,
Use the WGS-84 map datum, and
Display elevation in meters.

What If You Have Problems?

Time to lock sufficient satellites

The GPS receiver may require from about three (typical) to twenty (worst case) minutes to acquire a sufficient number of satellite signals to perform the measurement after it has been activated. The UNAVCO receivers are shipped with newly-installed and spare batteries, but if the receiver does not activate after depressing the ON/OFF button, then it may need new batteries.

The receiver is not displaying latitude or longitude

The receiver has many functions indicated on various display screens other than the "Location 1" screen that appears when the unit is initially powered up. Feel free to read the enclosed manual and use these other functions after making your site measurements. The "Location 1" screen will provide you with the position information necessary for your location measurement. After

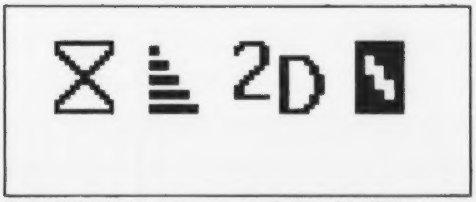

Figure GPS-P-3: Status icons on the display of the GPS receiver supplied by UNAVCO.

experimenting with other screens, depress the LOC button to return to the "Location 1" screen.

Status or poor signal quality icons appear

Do not record data if the icons in Figure GPS-P-3 appear. When the receiver has a good view of the sky, waiting or moving slightly will usually cause these icons to disappear. Standing close to the receiver or a group of people hovering around the receiver blocks the receiver's view to the satellites and causes intermittent signal losses which will prompt the icons to appear. Stand back or hold the receiver high. In thick foliage or heavy canopy, the receiver may be unable to lock to the requisite four satellites. Because the satellites move in the sky, trying again at a later time may provide better results. If problems persist due to obstructions, perform *Offset GPS Measurements Protocol*.

If you do not have access to the School Site Location Data Entry Sheet or Site Selection Data Entry Sheets on the GLOBE Student Data Server, please send a copy of the completed work sheet for each site's measurements to UNAVCO (address given above). You may return the completed work sheets with your receiver if you used a GPS receiver provided by the GLOBE Program through UNAVCO. Keep a copy of your data with all the other GLOBE observations made by your school.

Many schools worldwide are sharing a limited number of receivers. Experiment with and enjoy them while you have them, but please return borrowed receivers in a timely fashion to help the next school.

Data Submission for the GPS Measurement

After making your field GPS measurements and averaging the position data, submit your results via the Data Entry Sheets. Copies of these sheets are included in the appendices of the appropriate investigations in this Guide. The appendix to this investigation has the School Site Location Data Entry Sheet. The latitude and longitude should be rounded to the nearest 0.01 minutes as displayed on your receiver. For each of your sites, the data requested include:

Recorded Value	Units
Averaged latitude	[degrees, minutes, such as 35 degrees 20.27 minutes North]
Averaged longitude	[degrees, minutes]
Averaged elevation	[meters]
Time of initial recording	[year, month, day, UT hours, and minutes]
Type of receiver	UNAVCO numbers or manufacturer, model number, and serial number
Other	Information as requested

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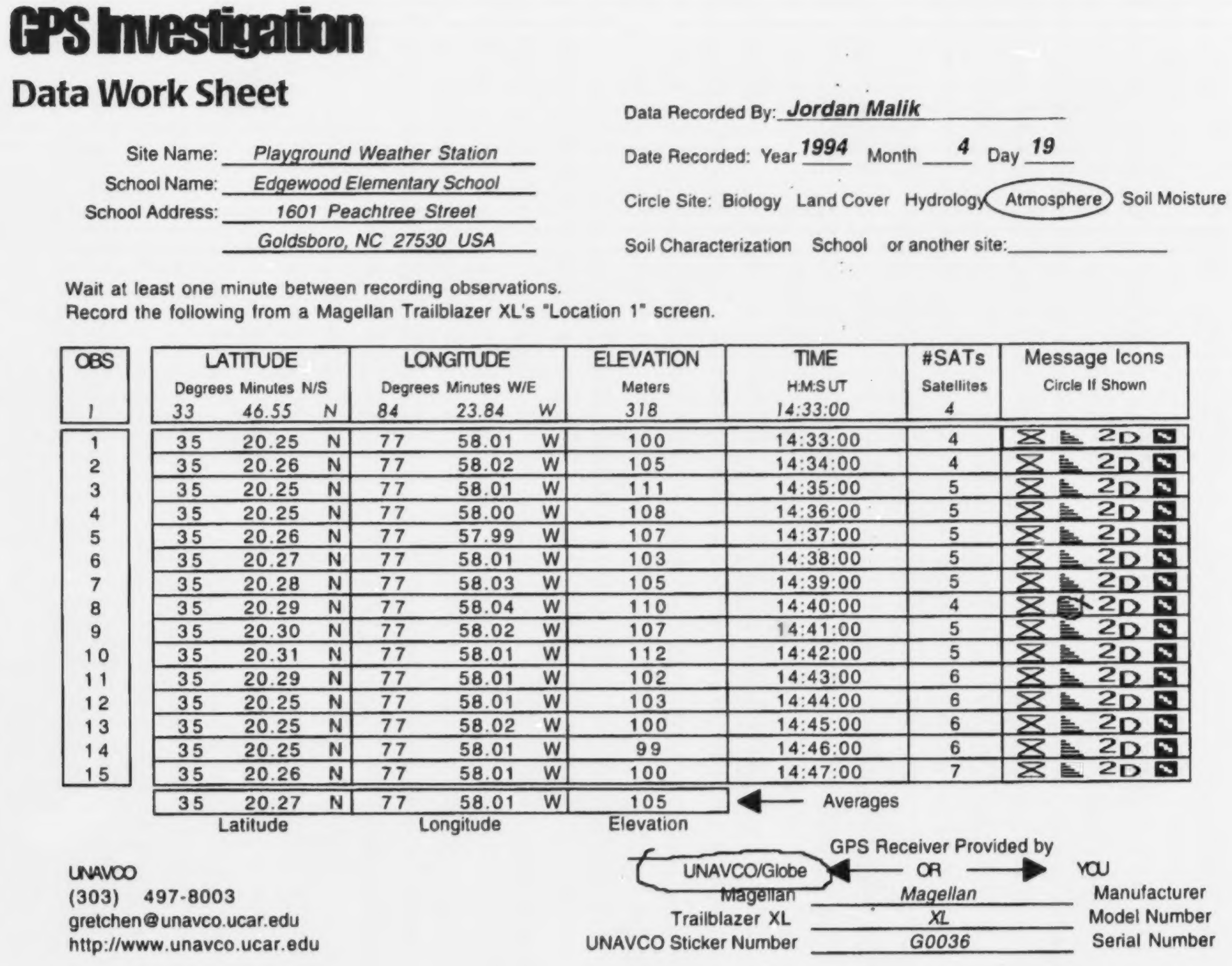
Figure GPS-P-4: An Example GPS Investigation Data Work Sheet



GPS Investigation

Data Work Sheet

Site Name: *Playground Weather Station*
School Name: *Edgewood Elementary School*
School Address: *1601 Peachtree Street*
Goldsboro, NC 27530 USA

Data Recorded By: ***Jordan Malik***
Date Recorded: Year ***1994*** Month ***4*** Day ***19***
Circle Site: Biology Land Cover Hydrology [✓ Atmosphere] Soil Moisture
Soil Characterization School or another site: ________

Wait at least one minute between recording observations.
Record the following from a Magellan Trailblazer XL's "Location 1" screen.

OBS	LATITUDE			LONGITUDE			ELEVATION	TIME	#SATs	Message Icons
	Degrees	Minutes	N/S	Degrees	Minutes	W/E	Meters	H:M:S UT	Satellites	Circle If Shown
1	*33*	*46.55*	*N*	*84*	*23.84*	*W*	*318*	*14:33:00*	*4*	
1	35	20.25	N	77	58.01	W	100	14:33:00	4	⧗ ◢ 2D ▣
2	35	20.26	N	77	58.02	W	105	14:34:00	4	⧗ ◢ 2D ▣
3	35	20.25	N	77	58.01	W	111	14:35:00	5	⧗ ◢ 2D ▣
4	35	20.25	N	77	58.00	W	108	14:36:00	5	⧗ ◢ 2D ▣
5	35	20.26	N	77	57.99	W	107	14:37:00	5	⧗ ◢ 2D ▣
6	35	20.27	N	77	58.01	W	103	14:38:00	5	⧗ ◢ 2D ▣
7	35	20.28	N	77	58.03	W	105	14:39:00	5	⧗ ◢ 2D ▣
8	35	20.29	N	77	58.04	W	110	14:40:00	4	⧗ [✓ ◢] 2D ▣
9	35	20.30	N	77	58.02	W	107	14:41:00	5	⧗ ◢ 2D ▣
10	35	20.31	N	77	58.01	W	112	14:42:00	5	⧗ ◢ 2D ▣
11	35	20.29	N	77	58.01	W	102	14:43:00	6	⧗ ◢ 2D ▣
12	35	20.25	N	77	58.01	W	103	14:44:00	6	⧗ ◢ 2D ▣
13	35	20.25	N	77	58.02	W	100	14:45:00	6	⧗ ◢ 2D ▣
14	35	20.25	N	77	58.01	W	99	14:46:00	6	⧗ ◢ 2D ▣
15	35	20.26	N	77	58.01	W	100	14:47:00	7	⧗ ◢ 2D ▣
	35	20.27	N	77	58.01	W	105	← Averages		
	Latitude			Longitude			Elevation			

GPS Receiver Provided by
[✓ UNAVCO/Globe] ← OR → YOU
Magellan *Magellan* Manufacturer
Trailblazer XL *XL* Model Number
UNAVCO Sticker Number *G0036* Serial Number

UNAVCO
(303) 497-8003
gretchen@unavco.ucar.edu
http://www.unavco.ucar.edu

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Offset GPS Protocol

Purpose

To determine the latitude and longitude of a site where a GPS receiver is unable to make an accurate measurement

Overview

After identifying locations where we wish to know a latitude and longitude but are unable to make a direct GPS measurement, students will move north or south until they can perform a successful GPS measurement at an offset site. They will determine the offset location's latitude and longitude and the distance between the sites. Then they will calculate the location of the desired site.

Time

One class period

Frequency

Once per site

Level

Intermediate and Advanced

Key Concepts

- The latitude and longitude of a location can be inferred from its relationship to a nearby known location.
- Magnetic Variation

Skills

- *Determining* your local magnetic variation
- *Using* a compass to determine true north and south
- *Measuring* length with a tape
- *Determining* location as an offset from another location
- *Adding* and *subtracting* of angles measured in degrees and minutes

Materials and Tools

- GPS Receiver
- Magnetic compass
- Tape measure
- Pencil or pen
- Offset GPS Data Work Sheet for recording measurements and computing results

Preparation

Identify sites where you would like to make a GPS location measurement but cannot because the signal is blocked.

Determine your local magnetic variation (see below).

Prerequisites

Understanding of *GPS Protocol*
Geometry

Background

What if you cannot make a GPS latitude and longitude measurement at a study or sample site because the GPS satellite signals are obscured by thick foliage or a building? See Figure GPS-P-5.

You can move to a nearby location offset from your site where the GPS receiver can receive the satellite signals. You then can determine the location of your desired site by measuring the compass direction and distance between the offset location and your site. In general, you need to use trigonometric skills to determine the desired location. However, if you restrict yourselves to moving directly north or south from the your site, you can determine the latitude and longitude of your site using only arithmetic and some knowledge about our planet.

Our planet is almost a sphere. All circles of circumference that intersect the equator and each pole are the same size and are called meridians. By dividing Earth's circumference of 40,074 kilometers by 360 degrees, we learn that there are 111.32 kilometers in a degree of circumference. By again dividing this by 60, we

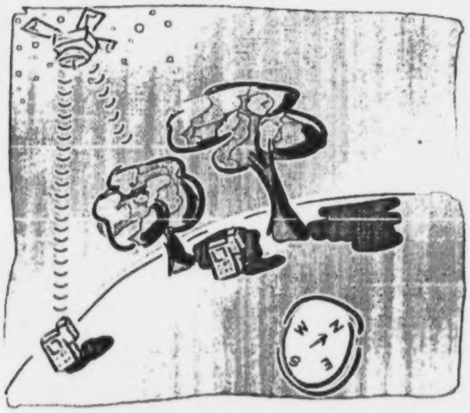


Figure GPS-P-5: Clear and blocked views to a GPS satellite

learn how many kilometers or meters are in one minute of circumference (1.855 km/minute or 1855 meters/minute). GPS receivers typically present locations to the nearest 0.01 minutes, which is 18.55 meters of latitude on Earth. (Why do GPS receivers present results to the nearest 0.01 minutes? See GPS Activity *Working with Angles*.)

Knowing the distance north or south between your site and an offset location allows you to determine the difference in their latitudes. For typical walking distances, this will be fractions of a minute.

Magnetic Variation

On Earth, the magnetic north and south poles do not line up exactly with the true north and south poles (along our planet's spin axis). Presently, Earth's magnetic north pole is slowly moving and located in Canada's North West Territories about 11 degrees away from the North Pole. Additionally, magnetic properties of Earth's composition vary slightly between locations contributing a unique distortion to Earth's magnetic field at any given site.

Consequently, a typically small variation of a few degrees must be added or subtracted from magnetic compass bearings to determine the direction of true north. This magnetic variation depends on your location. For example, near the Atlantic coast of North Carolina, USA, a compass needle points about 8.5 degrees west of true north. During one recent year, this difference changed about one tenth of one degree in Wisconsin, USA demonstrating that substantial changes can occur during your lifetime and quickly antiquate contemporary charts and maps which indicate magnetic variation.

How important is correcting for this potential source of error? If you were to use a compass to travel north by 100 meters in coastal North Carolina without compensating for the 8.5 degree local magnetic variation, you would be about 15 meters west of a line to true north. If you were trying to identify a particular 30 by 30 meter Landsat pixel, this might put you up to half way into the adjacent pixel.

You can learn the value and direction of your local magnetic variation by asking a local surveyor, asking someone who uses topographical, nautical, or aeronautical charts, or looking on similar navigation charts yourself.

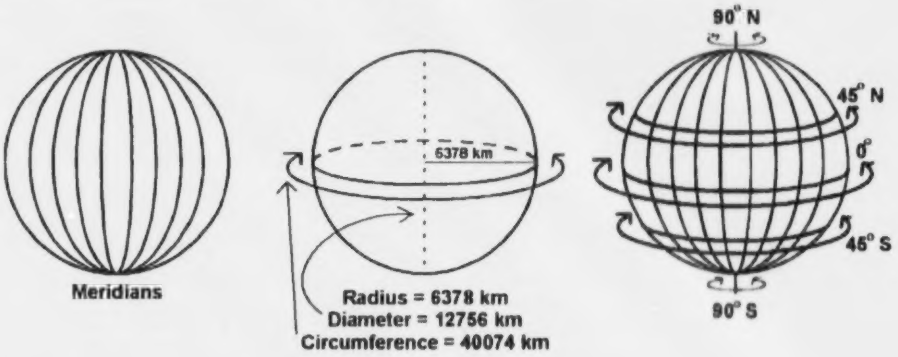
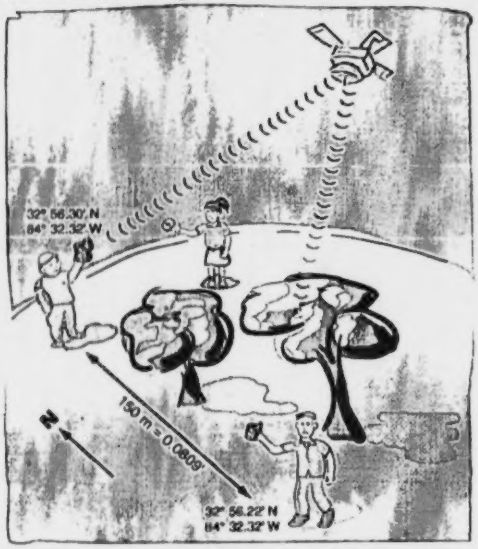


Figure GPS-P-6
Meridians, Dimensions, Lines of Constant Latitude

Figure GPS-P-7: Students performing measurements in Offset GPS Data Work Sheet, Figure GPS-P-8.

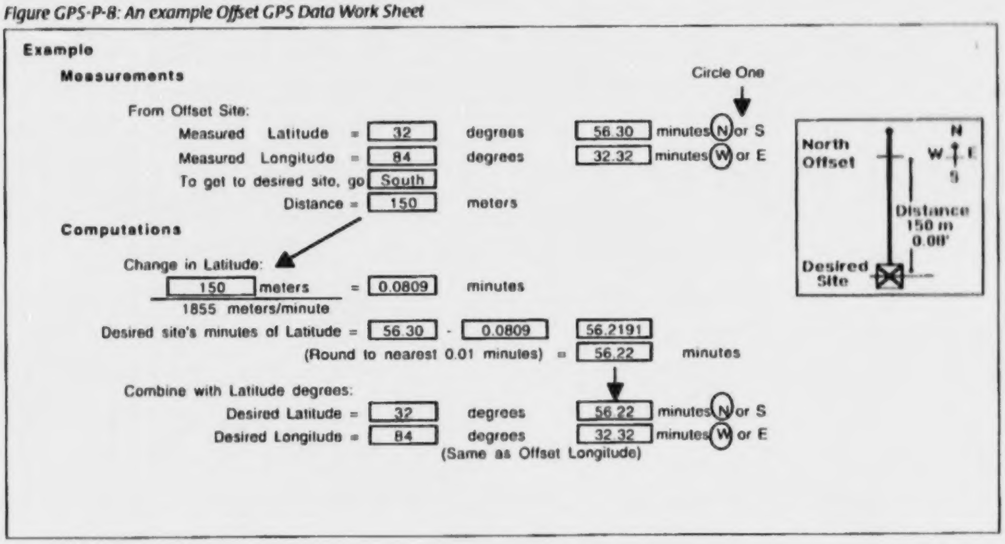


How to Determine Location Using GPS Readings from an Offset Location

1. Determine your local magnetic variation.
2. Go to your desired site. Mark it. Attempt to perform the GPS protocol to confirm that a good GPS measurement is difficult.
3. Use the compass to determine magnetic north. Correct this direction using your local magnetic variation, to determine true north.
4. Move either north or south to reach the nearest open area in which you can successfully perform the GPS protocol. This is your offset location.
5. Perform the *GPS Measurement Protocol* and record your latitude and longitude. Mark this as the offset location.
6. Record whether the offset location is north or south of your site.
7. Measure and record the distance between the offset location and your site. You may confirm a tape measure measurement with the pacing techniques discussed in the *Land Cover/Biology Investigation* procedure Determining Pace.
8. Divide this distance by 1855 m/minute to determine the latitude difference in minutes of the offset location from your site.

Add or subtract this value to or from the measured latitude value to determine the latitude of your site. See the *Working with Angles Learning Activity.* The longitude is the same as that of the offset location.

Figure GPS-P-8: An example Offset GPS Data Work Sheet


North Offset
N
W
E
S
Distance 150 m 0.08'
Desired Site

Example

Measurements

Circle One

From Offset Site:

Measured Latitude = 32 degrees 56.30 minutes [✓ N] or S

Measured Longitude = 84 degrees 32.32 minutes [✓ W] or E

To get to desired site, go South

Distance = 150 meters

Computations

Change in Latitude:

150 meters / 1855 meters/minute = 0.0809 minutes

Desired site's minutes of Latitude = 56.30 - 0.0809 56.2191

(Round to nearest 0.01 minutes) = 56.22 minutes

Combine with Latitude degrees:

Desired Latitude = 32 degrees 56.22 minutes [✓ N] or S

Desired Longitude = 84 degrees 32.32 minutes [✓ W] or E

(Same as Offset Longitude)

Learning Activities

What is the Right Answer?

Through a series of activities, students will learn that there are no "right" answers to some questions. A GPS receiver is optional.

Relative and Absolute Directions

A set of activities to introduce students to latitude, longitude, coordinates and relative and absolute directions. A GPS receiver is not needed.

Working with Angles

In these activities, students will learn about angles and how to arithmetically work with them. They will learn about degrees, minutes and seconds and how to convert them to decimal degrees. A GPS receiver is not needed.

Celestial Navigation

In this activity, students from two GLOBE Schools collaborate to determine their relative latitudes and longitudes using measurements of the sun's location in the sky.

What is the Right Answer?

Purpose

To introduce students to the concept that sometimes there is no one "right" answer to a question or measurement

Overview

Students learn to be careful when searching for a "right" answer to questions such as "What time is it?" by comparing multiple measurements of the time-of-day. Students gain an intuitive understanding of the characteristics of imperfect measurements. Using different clocks, students simultaneously record the displayed times. The resulting time measurements are converted from minutes and seconds to seconds. These measurements are plotted to illustrate the mathematical techniques of averages and deviations from an average.

Time

Approximately one class period

Level

Beginning levels - do only the clock comparison step

Intermediate and advanced levels - do the full activity

Key Concepts

Levels of measurement incorporate degrees of accuracy.

There are mathematical techniques for dealing with degrees of accuracy.

Skills

Comparing among multiple measurements of time

Plotting, graphing and *averaging* of data

Materials and Tools

At least one clock per student, any type which shows seconds will suffice

Paper and a writing tool for each student to record times

Copies of the GPS Investigation Time Measurements Work Sheet and plot forms for each student

Optional but desirable:

Calculator with addition, subtraction, multiplication and division functions

GPS receiver (Used as a source of standard time. Access to a GPS receiver is not essential. If available, use it as a highly accurate clock.)

Preparation

Provide at least 10 clocks for use by the class. The students can use school clocks or bring in clocks from home.

Prerequisites

Beginning levels - ability to read time on a clock

Intermediate and advanced levels - plotting and graphing skills

Background

GPS measurements will be made by a large variety of instruments scattered over large geographic regions and long periods of time. Efforts have been made to recommend instruments of sufficient accuracy and resolution to suit the underlying scientific goals. However, there will be variations between the measurement values because of the diversity of instrument conditions and student researchers.

What Is the Right Answer?

When people make measurements, they usually wish to know something about the quality of their acquired values. Typically someone asks, "How far am I from the right answer?" or "Did I get the right answer?" This assumes that there is a right answer against which to compare the measured value.

Sometimes there is a right answer. However, when scientists begin measuring a quantity, especially if it is the for first time, there may not be a standard against which to compare one's results. If you have the only instrument for making a particular measurement and you have no reason to doubt the values that you are recording, then it is reasonable to consider yourself to be the standard.

A problem comes when there exist either multiple measurement instruments or someone claims to be able to produce "the right" or better results. It has been said, "Someone with two watches does not know the time." In this case, you, the scientist, have to decide how to handle potentially different measurement values or how to choose to which measurements and standards to use.

Resolution and Accuracy Using Clocks

The number of digits or the smallest unit of time that can be read reliably by a person observing a clock is called the instrument's resolution. Thus a digital clock that displays 12:30:21 (meaning 12 hours, 30 minutes, and 21 seconds) has a resolution of about one second because the clock user can read the clock to the nearest second. An analog clock (which has hour, minute, and second hands) also has a resolution of about one second because you can read the second hand to about one second. An analog clock with only hour and minute hands has a resolution of only about one minute unless you consistently can determine the location of the minute hand between individual minute markers.

However, the clock that can be read to a resolution of 1 second can deviate from some standard time source from a fraction of a second up through a few hours. The ability of a clock to maintain "correct" time is called its accuracy. Therefore, if you have a clock that gains 10 minutes every day, you still may be able to read it to a resolution of a single second, but it is accurate to only 10 minutes per day. Some say that this clock has an error of 10 minutes per day.

Clocks are machines that display a count of something that changes as time passes. Early clocks determined time by counting falling drops of water or grains of sand. These were not particularly accurate because size of water droplets or an amount of sand falling is hard to control. Later clocks counted the swings of pendulums, the vibrations of tuning forks, mechanical oscillations in electrically stimulated crystals, and atomic resonances. Each of these subsequent clocks is more accurate than its predecessor, and all depend on the increased stability and repeatability of an underlying cyclical physical process. See Figure GPS-L-1.

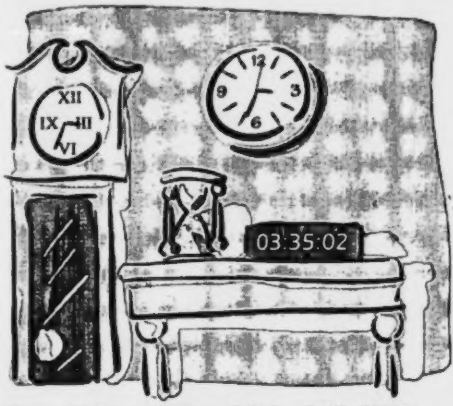


Figure GPS-L-1: A collection of clocks, all with different accuracies and resolutions.

For all clocks to display the same time, ideally each clock would have to be set to the same time simultaneously and experience the same environmental and mechanical conditions. This rarely happens. Clocks typically are set at different times from different references, having different accuracies, with different constructions, and experience different environments. A given collection of clocks will tend to offer a collection of slightly varying time values. This variation in measurement values will be true of most instruments for the temperature, distance, and other measurements of the GLOBE Program (thermometers, tape measures, etc.).

In the case of deciding when to feed a pet, an error of a few minutes from day to day may be insignificant. However, a Global Positioning System location measurement depends on the clocks onboard the satellites being highly accurate. An error of a single microsecond (1/1,000,000 second) may cause the displayed

GPS location to be in error by more than 300 meters. The desired resolution and accuracy depend on you (the user) and your understanding of your application.

Time Standards

Until the advent of the American railroads in the late 1800s, there were few widely accepted standards for time. Each population center had its own clocks that were usually referred to local solar noon when the sun peaks in the sky or some other celestial event. However, once one moves through 15 degrees of longitude or about 1600 kilometers along the equator, the time of local noon has changed by an hour. To facilitate consistent scheduling across continent-sized areas of our planet, time zones were created and implemented. The railroads needed and presented a common time reference frame.

Today all time zones are referenced to a longitude of 0 degrees that goes through Greenwich, England. Greenwich houses one of the great astronomical observatories. It was established for standardization of time for British naval navigation. Thus, the time in Greenwich, England, is used as a standard and is called Greenwich Mean Time (GMT), Universal Time (UT), or sometimes Zulu time. (Zulu refers to zero or the 0 degree longitude.) In the GLOBE GPS Protocol you will use the Universal Time (UT) designation for your measurements.

The Navy and the National Institute of Standards and Technology (NIST) within the United States and telephone companies maintain standard times using highly accurate atomic clocks that count the vibrations of a variety of atoms under well-defined conditions. The U.S. radio station with the call letters WWV continuously broadcasts the time of day in English on the short-wave radio frequencies of 5, 10, 15, 20, and 25 MHz from Boulder, Colorado. These frequencies themselves are locked to atomic time standards. The Canadian government provides a similar service in both English and French with their short-wave radio station CHU on 7.335 and 14.670 MHz. Many such services exist globally.

The Global Positioning System

The Global Positioning System has a series of satellites that broadcast timing signals from highly-accurate onboard atomic clocks. Therefore, a GPS receiver can determine its time to an accuracy comparable to that of the clocks on the satellite. The GPS receiver can even remove the delay due to travel time between the satellite and the terrestrial receiver because the receiver knows both the satellites' and its own locations. Thus, GPS receivers have become the best alternative to having your own atomic clock.

Telecommunications

Computer communication depends on time measurements that must be substantially more accurate than the rate at which the data flows. If one is using a 14.4k bit/second modem to transfer data via the Internet, a new information bit may be presented to the modem every 1/14,400 seconds or 70 microseconds. Thus, the clocks in the computer hardware must have sufficient resolution to separate each individual 70 microsecond slice of time and must be sufficiently accurate between the transmitting and receiving computers' clocks so as not to become unsynchronized by more than a fraction of the 70 microseconds. These needs are met easily by the use of quartz crystals that can be made to vibrate mechanically at chosen values of between 10 thousand and 100 million times per second. The vibrations are electronically counted by a digital circuit to determine the amount of time which has passed.

What To Do and How To Do It

Step 1: Get the Clocks

Locate at least ten (and preferably more) operating clocks that display time to a resolution of one second. Assign a student to each clock, and declare one student to be the master timekeeper. In a classroom situation where many students may have wrist watches with one second resolutions, these clocks will suffice. Wall clocks displaying seconds in a variety of different rooms are also adequate. Each student should be prepared to record a time and be able to see or hear the master timekeeper.

Step 2: Take the Measurements

Centrally locate the master timekeeper. At 30 minutes and zero seconds after the hour, this student is going to indicate to the other students to record their clocks' displayed time values to the nearest second. Perhaps ten seconds before the designated time, the master time keeper may begin counting down aloud to prepare the other students.

Although any particular time will work, choosing 30 minutes into the hour increases the chances that during the measurements no clocks will advance to the next hour and thus complicate later arithmetic processing.

Advanced students: Have the students perform the computations and graphing.

Other students: The teacher performs the computations and graphing outside of class for later presentation and discussion. While younger students may not understand the arithmetic, they do understand how the shape of the histogram plot appears for various clock accuracies.

Step 3: What Time was it?

For details, see the sample GPS Investigation Time Measurements Work Sheet and instructions.

For help with conversion from minutes and seconds to total seconds, see the GPS Activity Working with Angles.

Determine the average of all time-of-day measurements.

To determine the average time of day when the data were recorded:

- Determine the number of seconds past the hour for each participant's recorded time.
- Add these seconds values to produce a sum.
- Divide by the number of participants to produce the average time.
- Convert this back to minutes and seconds and record.

Step 4: Are our clocks any good?

Determine deviation from the average.

For each participant, compute the difference of each participant's time value from the average. Do not keep the sign. All results are positive. Add these together to produce a sum. Divide this sum by the number of participants to produce the average deviation. The average deviation is a measure of how far each measurement is from the average time

Plot differences from the average of our recorded times. See Occurrences Versus Differences Work Sheet.

Each bin is 10 seconds wide and is 10 seconds from the average number of seconds. Record the average number of seconds in the center box. Place an X in the appropriate bin for each participant's number of seconds into the hour. This type of plot is called a histogram.

How would the plot be different if we had a more or less accurate collection of clocks?

Further Investigation

If you have access to a GPS receiver, use its time to set a clock that can be used as the master clock for the measurements. The GPS receiver's displayed time will probably be the most accurate time available.

If we have higher quality clocks, how will our computed average deviation change?

Students with access to spreadsheet computer programs may wish to automate the arithmetic computations found on the work sheet.

Advanced students may wish to investigate the statistical concepts of standard deviation and variance.

Student Assessment

Quantitative

Ask students how the histogram plot would be different if they had a better or worse collection of clocks. Better: X's grouped closer together. Worse: further apart. Could they record clock values? Could they understand the arithmetic? Should any of the data be rejected? If a data sample is obviously inappropriate, such as from a stopped clock, yes!

Qualitative

The student should be able to describe situations in which it is and is not reasonable to demand a "right" answer.

The student should be able to list examples of measurements that they make in their lives and should contrast between the available and desirable resolutions and accuracies for these measurements.

The student should take responsibility for determining the accuracy and resolution necessary for the measurements required by an investigation.

Figure GPS-L-2: An Example Time Measurements Work Sheet

GPS Investigation

Time Measurements Work Sheet

Your Name: Jordan Malik

Today's Date: April 14, 1994

Participant Number	Recorded times (Hr	Min	Sec)	Seconds past the Hour (Seconds)	Average (Seconds)	Difference from Average (Seconds)	Average of Differences (Seconds)
1	12	30	0	1800		6.9	
2	12	29	54	1794		12.9	
3	12	30	1	1801		5.9	
4	12	30	15	1815		8.1	
5	12	31	1	1861		54.1	
6	12	30	25	1825		18.1	
7	12	30	3	1803		3.9	
8	12	30	7	1807		0.1	
9	12	29	22	1762		44.9	
10	12	30	1	1801	1806.9	5.9	16.08
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Ten Students Participated

1806.9 Average Number of Seconds into the Hour

Sum divided by number of Participants

16.08 Average Deviation

Difference Sum divided by number of Participants

10 = No. of Participants

18069 = Sum

160.8 = Difference Sum

Average Time

(Minutes)	(Seconds)
30	6.9

Instructions

Record Times

Computations

Determine the number of seconds past the hour for each participant's recorded time.

(Total Seconds = Minutes x 60 + Seconds)

Determine the average time.

(Average time = Sum of seconds / Number of participants)

Compute the difference of each participant's time value from the average.

(Difference = Seconds into the Hour - Average Seconds)

(Do not keep the sign – All results are positive numbers)

Determine the averages of the differences.

Plot Histogram

Record the average number of seconds in the center box.

Each bin is 10 seconds away from the average and 10 seconds wide.

Determine the time for each bin by adding or subtracting from the average.

For each number of seconds into the hour, place an "X" in the nearest bin.

(The number of X's should be the same as the number of participants.)

GPS Investigation

Time Measurements Work Sheet

Your Name: ____________________

Today's Date: ____________________

Participant Number	Recorded times *(Hr Min Sec)*	Seconds into the Hour *(Seconds)*	Average *(Seconds)*	Difference from Average *(Seconds)*	Average of Differences *(Seconds)*
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11			Average Number of Seconds into the Hour		Average Deviation
12					
13					
14					
15					
16					
17					Difference Sum divided by number of Participants
18			Sum divided by number of Participants		
19					
20					

10 = No. of Participants

______ = Sum

______ = Difference Sum

Average Time

(Minutes)	*(Seconds)*

Instructions

Record Times

Computations

Determine the number of seconds into the hour for each participant's recorded time.

(Total Seconds = Minutes x 60 + Seconds)

Determine the average time.

(Average time = Sum of seconds / Number of participants)

Compute the difference of each participant's time value from the average.

(Difference = Seconds into the Hour - Average Seconds)

(Do not keep the sign – All results are positive numbers)

Determine the averages of the differences.

Plot Histogram

Record the average number of seconds in the center box.

Each bin is 10 seconds away from the average and 10 seconds wide.

Determine the time for each bin by adding or subtracting from the average.

For each number of seconds into the hour, place an "X" in the nearest bin.

(The number of X's should be the same as the number of participants.)

Figure GPS-L-3: An Example Occurrences Versus Differences Work Sheet

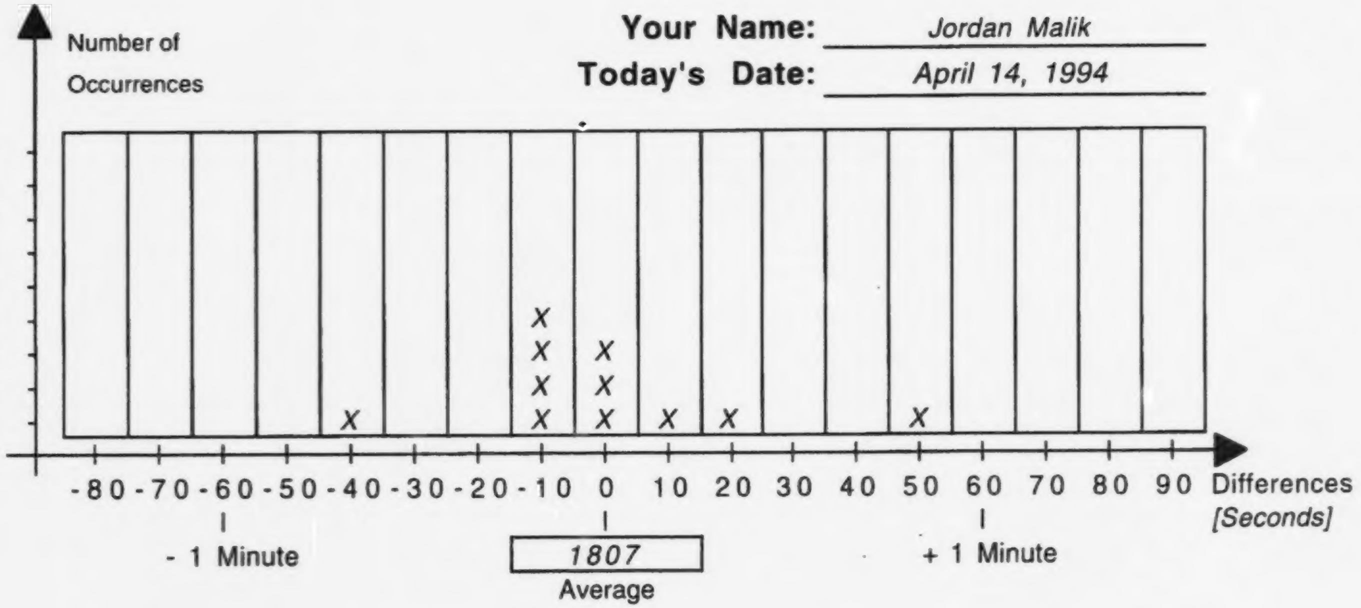
GPS Investigation

Occurrences Versus Differences Work Sheet

Plot 1: Histogram of Number of Occurrences versus Differences

Your Name: *Jordan Malik*

Today's Date: *April 14, 1994*



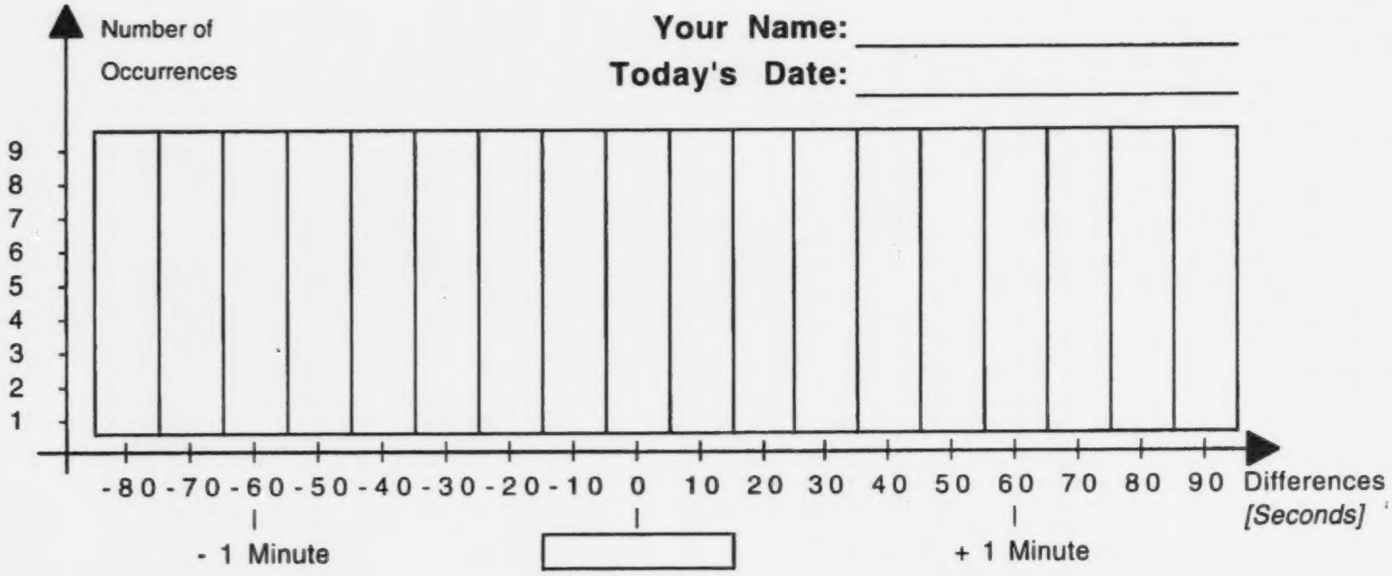
GPS Investigation

Occurrences Versus Differences Work Sheet

Plot 1: Histogram of Number of Occurrences versus Differences

Your Name: ____________________

Today's Date: ____________________



Relative and Absolute Directions

Purpose

Learning about latitude and longitude
Developing math skills

Overview

Students begin by asking the simple question: "Where Am I?" Then they learn about the magnetic Earth and the use of compasses and angles. Students also learn about the difference between relative and absolute locations. Throughout this activity, students practice using a variety of math skills.

Time

From one to five class periods depending on which steps you choose to do

Level

All levels with some exceptions noted

Key Concepts

- Relative and absolute direction
- Latitude and longitude
- Angles
- Use of magnetic compass
- Basic mapping

Skills

- *Distinguishing* between and *describing* relative and absolute directions
- *Communicating* location to another person
- *Describing* locations by using grids
- *Using* a magnetic compass to accurately determine angular direction
- *Developing* basic mapping technique

Materials and Tools

- Paper and pencil
- Graph paper
- Magnetic compasses
- Drawing compasses (for drawing circles)
- Globes
- Metric rulers and meter sticks
- Bar magnet

Preparation

None

Prerequisites

Beginning levels: Students should be at the appropriate developmental level to be able to learn about the use of latitude and longitude to find a location.

Intermediate and advanced levels: Basic understanding of degrees, angles and coordinate systems.

Special Note

If your students already understand latitude and longitude, then either you can proceed to the next activity entitled: *Working with Angles* or you can use some or all of these activities to provide a deeper mathematical understanding of relative and absolute directions on Earth.

Background

The GLOBE program uses GPS receivers to determine the latitude and longitude of GLOBE study sites. However, the ideas of latitude and longitude, coordinates attached to absolute reference systems, or angles from north may be new to many students. This set of activities introduces these concepts.

When you ask students, "Where are you?", they may respond, "At home" or "At school." The answers are in their own local reference frame.

If you use a magnetic compass to determine the direction to a tree that is north of you, you will probably conclude that the tree is to your north. However, if you move east or west by any substantial amount and use the same compass to determine your direction to the same tree, you will find the tree to be to your northeast or your northwest. Neither the tree nor Earth's magnetic poles have moved, but your compass indicates a different direction to the tree. There is something absolute about the positions of the tree and the poles, but there is something relative about your measurement technique. The starting point moved.

If we impose a gridded coordinate system upon our geographic area of interest or the entire world and number the various lines on the grid, we now have a reference frame in which we can uniquely determine any location independent of the relationship between your location and that of another individual. Latitude and longitude are the names of the values for the coordinate system in which we shall be working for geographic determination of locations with the Global Positioning System.

What To Do and How To Do It

Step 1. Relative Positions: Where am I? (For all levels)

Have students ask themselves the question, "Where am I?" and have them list words or draw a rough picture of where they are. Lead a class discussion on what defines "where are we?"

Encourage questions and time for reflection on where a person is and how one might explain where anyone was. Good questions for students to ask are: How can you describe your location to another student: in your classroom? in another classroom? in another school in town? in another town? in another country? Did students describe their location using relative or absolute references? Emphasize their reference frames.

Step 2. Attempting to Impose a Reference Frame: The Magnetic Earth (For all levels)

Our planet projects a gigantic magnetic field as if it contained a large bar magnet. See Figure GPS-L-4. Another magnet (like a magnetized needle) will be attracted to our planet's magnetic poles. A magnetic compass contains a magnet which can spin freely and be observed. Thus, magnetic compasses are useful navigational instruments because they allow one to see the direction of Earth's magnetic field, which almost lines up with Earth's north and south poles.

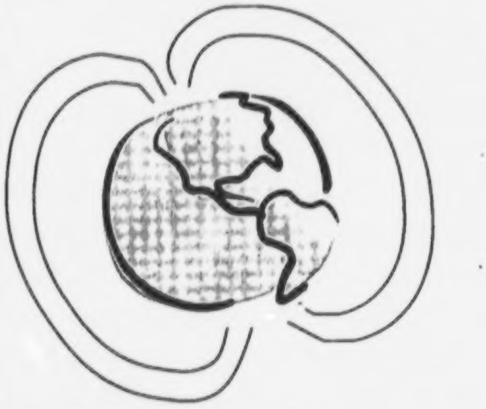


Figure GPS-L-4: The Earth as a Giant Magnet

Suspend a bar magnet on a string away from large metal objects and allow the magnet to stop any rotation or spin. Attach the string to the ends of the magnet as shown in Figure GPS-L-5.

Ask students what will happen. The magnet will eventually stop spinning so that its poles are aligned with north and south directions. Students can test the north-south direction by comparing the magnet with a magnetic compass.

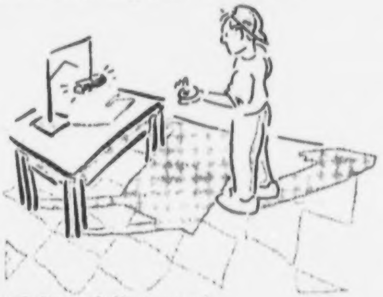


Figure GPS-L-5: Suspended bar magnet

To use the compass, hold the compass on your fingers of your outstretched hand and arm. Hold the compass flat relative to the ground so that the needle can move freely, and keep it away from all metal objects. Position yourself so that you can look across the compass through north while waiting for the needle to stop moving. *Do not place the compass near the magnet; it will lessen the effectiveness of the compass.*

Step 3. Introductory Compass Angles (For beginning levels)

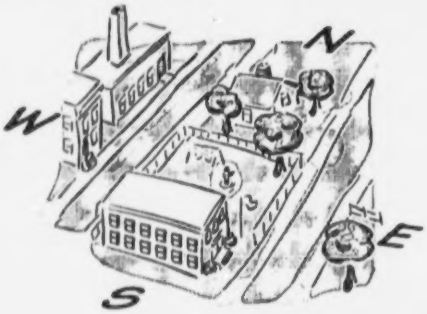
On a blank sheet of paper, record the following observations, using a magnetic compass for direction.

- Record your specific location (e.g., on the big rock outside our classroom window) and the date.
- List all things that are directly to your north (use the compass to find your direction), east, south, and west, then write a descriptive paragraph on each direction.

Chances are that you will not see the variety illustrated, but with a careful observation, you will notice specific differences in each direction.

Tip. Be specific about what is seen and the direction it is from you. Also record only permanent foreground and background objects. In areas where there are many things that look similar, try to pick out specific differences.

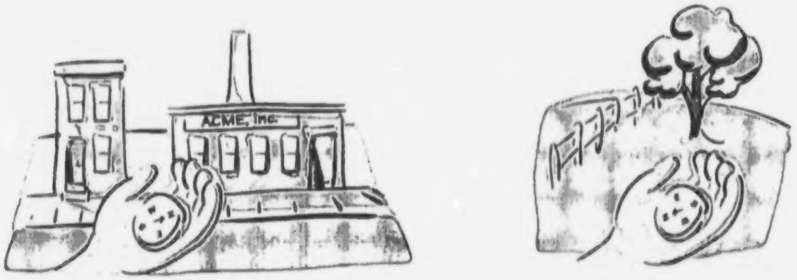
Figure GPS-L-6: A panoramic view



Remember that good scientists are specific in their descriptions and their drawings. They compare and contrast in their observations. Examples would include the following descriptions at two different schools. See Figures GPS-L-6, GPS-L-7a and 7b.

1. The red-brown brick building with the green window frames is due west. To the north of that building is the factory with the tall smoke stack.
2. The area to the east has a single oak tree with a fence extending away from the observer.

Ask questions about the observations to encourage students to compare and contrast.



Figures GPS-L-7a and GPS-L-7b: View from a school site facing west, view from a school site facing east

Step 4. Intermediate and Advanced Compass Angles (For intermediate and advanced levels)

You can divide a circle around you into 360 degrees. This is also written as 360°. See the GPS Learning Activity *Working with Angles* . Navigational directions from some location are given as angles around such a circle, with north at the starting place, or 0°. East is 90°; south is 180°; and west is 270°.

Angular Directions from North

Your hand can be used to measure directional angles effectively. As illustrated in Figure GPS-L-8, if you extend your arm, make a fist, and then extend your thumb, the width of your hand (with thumb extended) is about 15° (you may need to extend the little finger as well). That means that six of your hands with extended thumbs would fit between north and east. (Each fist with extended thumb equals 15°, because there are 90° between north and east, and 90° divided by six fists is 15° for each fist.)

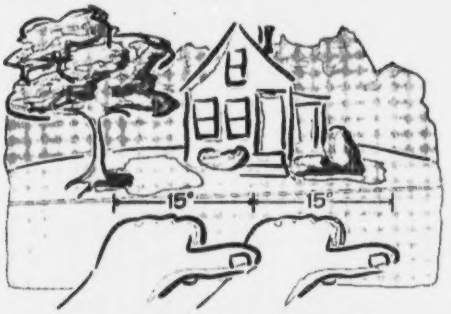


Figure GPS-L-8: Using your hand to measure 15°

Because the angular relationships of each individual's hand will differ slightly, you may find that you have to extend your finger slightly so that six "fists" fit into 90 degrees. You may need to try to measure six "fists" between north and east several times before you consistently get the same number of "fists" on repeated trials. Hold your hand as steadily as possible. Focus on what is at the tip of your thumb, then move your hand so that the back of your hand is now where your thumb tip was. Because you always take your hand with you, remember how you extended your arm and hand so that you can make future angle measurements.

Practice positioning your hand and thumb so that you get a consistent number of "hands" between north and east or north and west. Now record what you see at the end of each hand width. After you feel confident with your measurements go on to the panorama observations below.

Step 5. Panorama Observations (For all levels)

Take a sheet of paper and fold it lengthwise. Cut along the fold, so that you have two long halves of the paper. Tape two of the ends together and mark the four directions on the paper, as indicated in Figure GPS-L-9, so that north is on the two far ends and south is in the middle. Record all observations as drawings on the long narrow strip of paper.

Now that you have had experience with the magnetic compass and with the compass directions, position yourself in the same spot as you did for the compass activity. Draw a panoramic view of what the landscape looks like all around you by making multiple individual drawings for each of the four north, south, east, and west directions. Students can mark all the other directions that fall in between (south southeast, northwest by north), by measuring the angles with their fists.

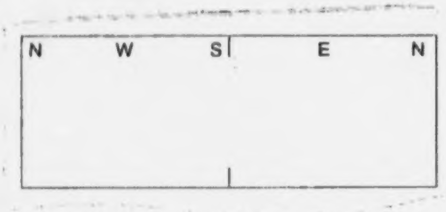


Figure GPS-L-9: Preparing the strip for drawing a panorama

To extend this step further, use your fist to measure time. Because the sun moves 15° per hour through the sky, one can estimate the time in hours until sunset by measuring the number of hand-widths from the sun to the western horizon. Knowing your local time of sunset, you can then work backward and estimate your local time without a clock!

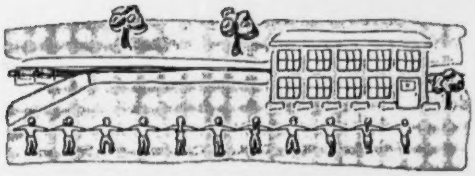


Figure GPS-L-10: Students lined facing a mark to the North

Step 6. Are the North, South, East, and West Directions Relative or Absolute? (For all levels)

Outdoors, mark a point about two meters above the ground (for example, crossed strips of tape on a school window), so that you can have the students stand along an east-west line south of the mark. Have the students form a line with the person on the far east due south of the mark. The students should be spaced at arms' length. See Figure GPS-L-10,

In Figure GPS-L-11, the boxes represent individual students. With compass in hand, the first student takes a bearing on the mark and finds that the direction is north and the angle is 0°. The students will then record "0°" in the box, marked "1." Have each student, in numerical order, make an angle measurement between north and the mark. Because all results will be between north and east for the scenario illustrated, all measurement results should be between 0° (north) and 90° (east).

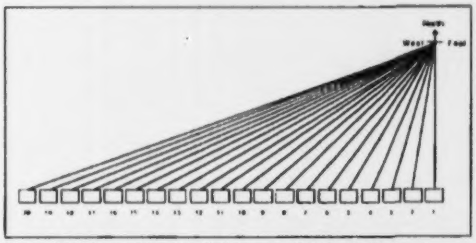


Figure GPS-P-11: Overhead diagram of students facing a particular mark

Why did each student get a slightly different measurement? Were they all not looking at the same point? Their compass angles are relative to their individual and different locations.

Step 7. Compass Directions Are Relative to Your Location (For all levels)

For practical purposes, Earth's north and south magnetic poles are fixed close to our planet's north and south spin axes. In the absence of other magnets, a magnetic compass needle aligns itself with Earth's magnetic field. Thus, its needle will point to Earth's magnetic poles. (The Earth's magnetic poles will not move much during our lifetimes.)

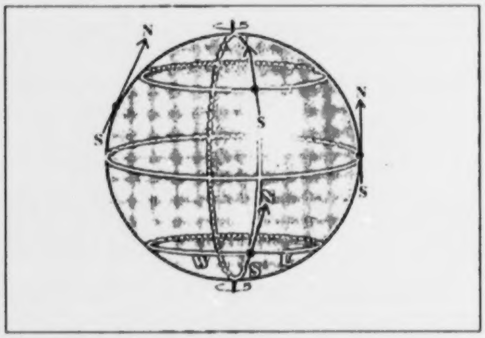


Figure GPS-L-12: The direction North as perceived at different points on Earth

Earth's magnetic poles appear fixed. However, an observer on the equator will claim the direction to the north as being along a line tangent to the equator. Another observer who is half way from the equator to the north pole will also claim that the direction north is a line tangent to the globe at his location. However, these two lines are not parallel. See Figure GPS-L-12. Therefore, they are not pointing in the same direction. Get a globe and try this for a variety of different locations around the world. You can see that the direction you call north depends on your location. Therefore, north, south, east, and west are relative directions. These directions are angle measurements in the direction of the magnetic north pole relative to the location from which the measurement is taken.

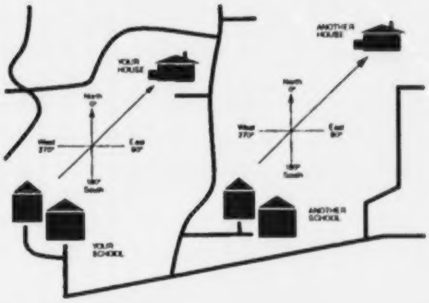


Figure GPS-L-13
Directions from home to school are different for everyone

Further background: Directions are not necessarily unique. What problems does this cause? Navigation between arbitrary locations requires a known point as a fixed reference. Giving directions to listeners who are located at different positions means that they must agree to some point in common before directions can be given. Unique starting and ending points (like trade routes), provide an absolute or fixed reference frame such as a coordinate system placed on a map. Latitude and longitude provide a similar reference frame for our spherical planet.

Use the drawing and map in Figure GPS-L-13 to help students understand relative and absolute directions and positions. See glossary. A full page version of Figure GPS-L-13 is included at the end of this Learning Activity. You may make duplicates for student use.

Describe how to go from your school to your house. Then describe how to go from another school to another house. Then ask, what is the difference?

A riddle about absolute directions: Someone builds a house. All of the outside walls of the house face south. A bear walks up to the house. What color is the bear? (Answer: White - if all sides of the house face south, then the house must be at the North Pole. The only bears in the Arctic Circle are polar bears.)

Step 8. Describing a Location (for all levels)

We wish to introduce absolute reference frames for describing locations. Students will expand upon past activities to answer the question "Where am I?" or "Where is something?" and will learn that they must specify the "where" with sufficient clarity so they can communicate their position unambiguously to someone else. We ask students to provide directions relative to some agreed-upon reference or some coordinate system instead of relative to themselves. Cartesian coordinates (x,y axes in geometry and algebra) and latitude and longitude on the globe provide such a system.

Place two students back to back, each with checker boards, so that each cannot see the other's board. Give them two checkers (tokens) and have one place the tokens anywhere upon the board. Without imposing further rules, have that student describe to the other student where to place the token, so that each token is in the same position on each board. Repeat the process beginning with the second student.

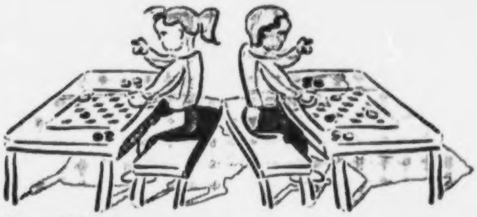


Figure GPS-L-14
Describing checker locations

Lead a discussion on the communication between the two students. How did the students choose to communicate the locations of their tokens? What determined the clarity and difficulty of their communications?

Step 9. Numerically Describing a Location (for intermediate and advanced levels)

Label a piece of graph paper or a drawn grid as shown in Figure GPS-L-15, Have students find positions communicated as follows: (1,2), where the first number describes the distance to move to the right from zero on the horizontal axis and the second number describes the distance to move up along the vertical axis.

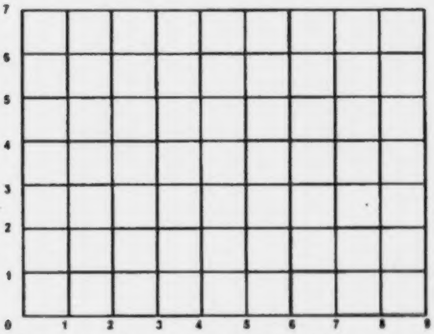


Figure GPS-L-15: Label a sheet of graph paper

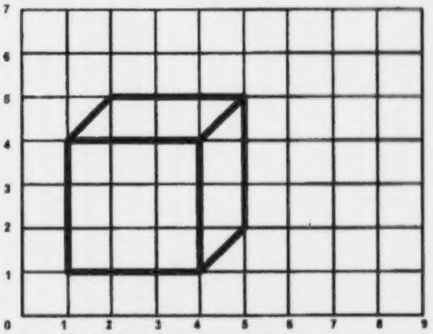


Figure GPS-L-16: The resulting simple picture

Then, have students draw a simple picture from the following lines between the given sets of positions. See Figure GPS-L-16.

(4,1) to (4,4) (4,1) to (5,2) (5,2) to (5,5)
(1,4) to (1,1) (1,1) to (4,1) (1,4) to (4,4)
(1,4) to (2,5) (2,5) to (5,5) (4,4) to (5,5)

Discuss what information is needed to communicate points and drawings. For example, each line required information about a starting point and an end point.

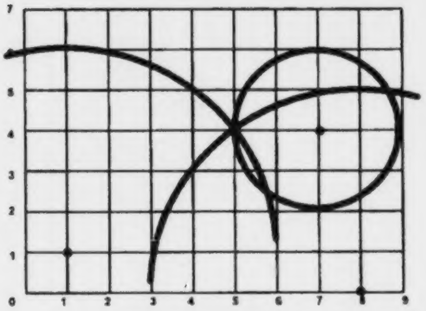


Figure GPS-L-17: Cartesian coordinates defining arcs

On a new piece of gridded paper, go to position (7,4), and draw an arc with a drawing compass that has a radius of two units. With position (1,1) as the center, draw an arc with a radius of five units that intersects the first arc. Finally, draw a third arc, with a radius of five units and which has a center at (8.0). Where do they intersect? How many arcs are needed to determine a point.

Suppose that the Cartesian coordinates in Table GPS-L-1 were mapping a portion of ocean and that the side of each square was the distance it

Table GPS-L-1

Ship	Location	Signal travel time milliseconds
Alexandria	(0,0)	4.0
Corsica	(1,5)	2.0
Hsuchou	(6,3)	3.5

Ship location and time for Bainbridge's signal to travel to each ship

Table GPS-L-2: Places on the Globe

Latitude	Longitude	Name
36°N	139°E	
60°N	30°W	
27°S	109°W	
90°S	0°E	
90°S	180°W	
—	—	Your location
—	—	Your opposite location

takes a radio signal to travel in one millisecond. There are three ships at sea, the Alexandria is at (0,0), the Corsica is at (1,5), and the Hsuchou at (6,3). Each ship receives a distress signal from a fourth ship, the Bainbridge. The time that it took the Bainbridge's distress signal to travel to the three potential rescue ships will help the ships locate Bainbridge's position. Can you find the distressed ship? (Measurement of signal travel times forms the basis of radar and GPS.)

Step 10. Describing Geographical Locations (for intermediate and advanced levels)

On a globe, the east-west lines are lines of constant latitude and the north-south lines are lines of constant longitude. Have students discuss how they are similar to and how they are different from the lines they found on the Cartesian coordinate system. Find the locations listed in Table GPS-L-2.

Take a globe and find your location. Estimate values for your latitude and longitude from the globe. Now find the point on the globe opposite your location and estimate its latitude and longitude. What are the relationships between the latitude and longitude coordinates for these two opposite locations?

Note: Steps 8, 9, and 10 present concepts similar to those in *Odyssey of the Eyes Learning Activity* in the *Land Cover/Biology Investigation.*

Adaptations for Younger and Older Students

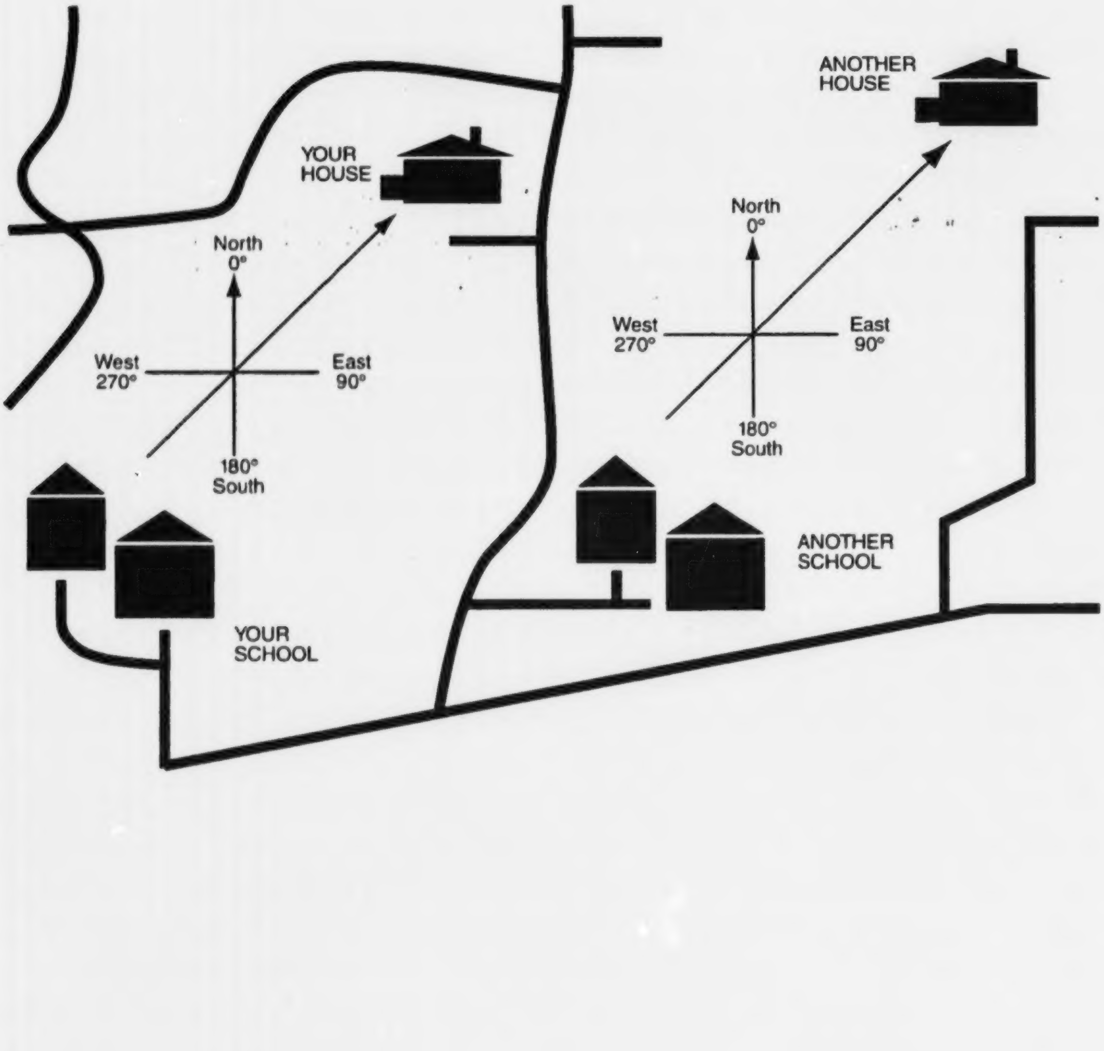
Qualitative descriptions of measurements may be more appropriate for younger students. For example, describing a compass direction as being "northeast" may be clearer than "45° from north." More quantitative and analytic techniques may be appropriate for older students. For example, they can use the Pythagorean Theorem to determine distances between locations in a flat, gridded coordinate system.

Student Assessment

Have students identify various cities or geographical features using latitude and longitude. Give them a list of cities and have them determine latitude and longitude for each. Also have them find distances between geographical locations.

GPS Investigation

School Site Location Map Graphic


ANOTHER HOUSE
YOUR HOUSE
North 0°
West 270°
East 90°
180° South
North 0°
West 270°
East 90°
180° South
ANOTHER SCHOOL
YOUR SCHOOL

GPS Investigation

Site Location Data Work Sheet

You will need at least one copy of this GLOBE GPS Data Sheet per GLOBE site. After making your field GPS measurements and averaging the position data, note your results on one of the GPS Data Submission Sheets, then submit your data to GLOBE. You can do this by accessing the GPS data entry page under the main GLOBE page **(http://www.glove.gov)** on the World Wide Web. You will be submitting the determined average location for each of your sites (Atmosphere, Land Cover, Biology, Hydrology, Soil Characterization, and Soil Moisture Study Sites and your school). The data submitted should be rounded to the nearest **0.01 minutes** as displayed on your GPS receiver.

Type of Site
(Atmosphere, Hydrology, etc.)

Site Description
(25 characters or less)

Averaged Latitude
(Whole Degrees, Decimal Minutes N/S)

Averaged Longitude
(Whole Degrees, Decimal Minutes E/W)

Time of 1st Observation
Hours: Minutes: Seconds in UT

Type of Receiver
Magellan Trailblazer XL & UNAVCO number

or

Manufacturer model number and serial number

Working With Angles

Purpose

Introduce students to the concept of an angle

Show that lines of latitude and longitude are derived from angle measurements of Earth

Demonstrate that angle units smaller than one degree are needed for GLOBE related measurements

Show how to report and compute arithmetically with various angle units

Overview

Students learn how to perform arithmetic and averaging on a set of angle values. In doing so, they learn the units for angles (degrees, minutes, seconds), how to convert between degrees, minutes, and seconds and decimal degrees, and why one might wish to perform this conversion.

Time

One to three class periods, depending on which activities are done

Level

Intermediate and advanced

Key Concepts

Angles are measured in degrees, minutes, seconds and in decimal degrees.

GPS receivers use degrees and minutes to measure angles.

Skills

Converting between angles measured in degrees, minutes, seconds and angles measured in decimal degrees.

Adding and *subtracting* of angles in degrees and minutes.

Averaging angles measured in degrees and minutes

Materials and Tools

None required. (A calculator with addition and division will speed the arithmetic.)

Preparation

None

Prerequisites

Addition, division, decimal fractions

Units of Angle Measurements: Degrees, Minutes, Seconds

Background

An angle is the measure of a circular distance. An angle is formed by two lines extending from the same point.

You can measure angles. The units for angles are degrees. A full circle is divided up into 360 degrees (or 360°).

Figures GPS-L-18 and GPS-L-19 illustrate some special angles.

What To Do and How To Do It

Have the students draw a pie and cut it into eight equal pieces. Ask them for the value of the angle formed at the point of one slice. 360°/8 = 45°

Some students may not have cut symmetrically through the center. Some may have cut into squares. Different students may have different assumptions. Discuss the various outcomes. Try again with 4, 10, and 12 pieces. Results are 90°, 36°, and 30° for radically symmetric slices through the pie's center.

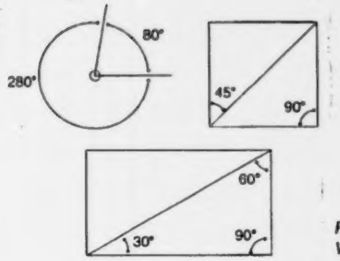


Figure GPS-L-18: Various angles

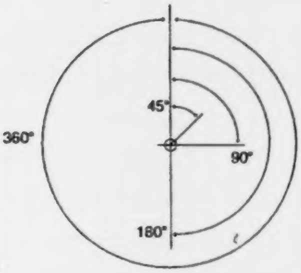


Figure GPS-L-19: Some special angles

More About Angles

Background

Longitude and latitude are angles measured around our planet's spin axis and between our equator and the poles respectively. Continental distances may span tens of degrees of latitude and longitude. However, over small distances, such as the size of a 30 meter by 30 meter GLOBE study site, the angular changes in latitude and longitude typically will be fractions of a degree or just a few arc seconds.

Small Angles – Sometimes you wish to measure an angle that is smaller than one degree. Each degree is divided into 60 minutes. You can say that one third of one degree is 20 minutes. Some people call this angle 20 "arc" minutes so as to avoid confusion between the measure of angles and the measure of time.

Although the moon is 384,500 kilometers distant and 3,200 km in diameter, it appears to be one half of one degree or 30 arc minutes across its diameter to an Earthbound observer. See Figure GPS-L-20. By interesting coincidence, our sun also appears to subtend the same angle in the sky; even though it is 148 million km distant and 1.3 million km in diameter. (This is why the moon covers the sun almost perfectly during an eclipse.)

For even smaller angles, each minute is divided into 60 parts called seconds or sometimes arc seconds.

Astronomers use degrees, minutes, and seconds to describe celestial angles. At its closest approach to Earth, the planet Jupiter appears to have an angular diameter of about 47 arc seconds. This is such a small angle that Jupiter looks like a point in the sky to most people but appears to be a disk when viewed through a small telescope or even binoculars. Viewing a coin at the far end of a playing field produces the same effect.

An example of the number describing the angular distance between two stars which are 3 moon widths apart might be 1 degree, 30 minutes, and 0 seconds. This can also be expressed with the symbols 1° 30' 0".

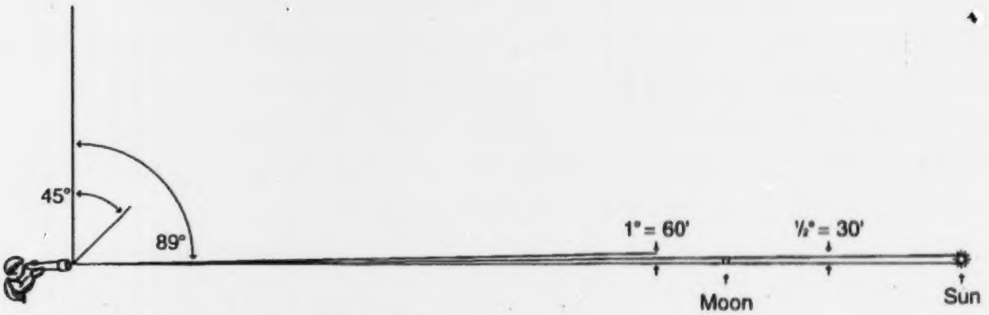


Figure GPS-L-20: 1/2 degree=30 minutes, sun and moon

Why Degrees, Minutes, and Seconds Exist and the Problem

The Earth takes about 365.25 days to travel around the sun. Early astronomers did not know this fact so they made calendars based on their observations of the positions of celestial bodies. They noticed that stars and their associated constellations tend to drift across the sky as seasons change, and about 360 days pass before stars return to the same places in the sky at the same time of night.

What To Do and How To Do It

Three hundred and sixty (360) is a comfortable number if you do lots of arithmetic. It is easily divided by many numbers.

Have students list whole numbers that easily divide into 360 and why they might be of cultural, historical, or physical importance. *Examples:*

2
3
4 (seasons)
5 (half of 10)
6
8
9
10 (fingers)
12
15
18
20 (fingers and toes)
24
30 (almost the time from one full moon to another)
90 (days in a season)

Because a circle repeats itself like a year, a circle was broken into 360 degrees. So 360 days in a year was the standard for a long time.

Measuring Earth with Angles·

Background

Because our planet is round, we can measure distances on the surface as angular differences from the Earth's center. One degree around the Earth's round surface is about 111 km. This distance was bigger than most people would travel. Therefore a smaller division was used. A degree is divided into 60 minutes. Each arc minute on the Earth's surface is defined to be one nautical mile (about 1.8 km), and sailors used the nautical mile for centuries. A speed of one nautical mile per hour is one knot. Although metric units have been globally accepted, both nautical miles and knots are units that continue to be used in some marine and aviation applications.

We continue to use degrees, minutes, and seconds to measure angles. However, the following angles are equivalent:

Quarter of a circle = 90°
Our moon's diameter = 0.5° = 30'
Jupiter's diameter = 0.013° = 0.79' = 47"

Although one could express Jupiter's diameter as seen from the Earth as being "Zero point zero one three degrees," "Thirteen milli-degrees," or "Thirteen thousandths of a degree," the usage accepted by most in the scientific community is: "Forty-seven arc seconds." People seem to like using whole numbers instead of fractions, and the use of minutes and seconds provides this for small angles. In contrast, people rarely describe 30 arc minutes as 1800 arc seconds or 90 degrees as 5400 arc minutes or 324,000 arc seconds.

The problem is that we now have several sets of units (degrees and minutes and seconds) with which we can express the same angle. Some units better facilitate our intuitive handling of angles of extreme differences in sizes, but these different units can complicate arithmetic with angles.

Conversion Between Units of Degrees, Minutes, Seconds and Decimal Degrees

The use of degrees, minutes, and seconds can be a problem if you need to relate several angles which are measured in different combinations of these units.

5° 45' 0" = 5.75°
0° 30' 0" = 0.5°

What if we wished to increase the first angle by half a degree (which is 30 minutes)? The new angle would be the result of adding together both angles. Although this could be handled by adding the degrees to the degrees and the minutes to the minutes, look what happens with this example. When you add 45 minutes to 30 minutes, the result is 75 minutes, which is more than a degree. Thus your new angle could be represented as 5 degrees, 75 minutes, and 0 seconds.

	Calculation	Result in decimal degrees
Seconds	9"/60/60	0.0025°
Minutes	15'/60	0.2500°
Whole Degrees	25°	25.0000°
Decimal Degrees		25.2525°

Table GPS-L-3: Converting 25 degrees, 15 minutes, 9 seconds to decimal degrees

However, now our number of minutes is larger than a whole degree. If this occurs, we prefer to increase the number of degrees by one and reduce the number of minutes by 60. This leaves us with an angle expressed as 6° 15' 0". Now the number of minutes is describing only part of one degree.

Some people perform much arithmetic with angles (surveyors, carpenters, draftsmen, astronomers). This arithmetic can become quite cumbersome, especially if the number of seconds is not zero. Therefore, we like to be able to convert between angles measured in degrees, minutes, and seconds and angles measured in decimal degrees. See Table GPS-L-3.

Degrees, Minutes, and Seconds to Decimal Degrees

You convert the seconds into decimal degrees by dividing them by 60 twice. Convert the minutes into decimal degrees by dividing them by 60 once. The whole degrees stay the same. Add all three numbers together to get the total number of decimal degrees. See Table GPS-L-3.

Decimal Degrees to Degrees, Minutes, and Seconds

You remove the whole number of degrees and work with the decimal fraction. Multiply this decimal fraction by 60 to produce decimal minutes. Remove the whole number of minutes and keep the decimal fraction. Multiply this decimal fraction by 60 to produce decimal seconds.

You combine the whole numbers of degrees and minutes with the remaining seconds to produce an angle with units of degrees, minutes, and seconds.

Why GPS Receivers use Degrees and Minutes

A Global Positioning Receiver is available for you to borrow from GLOBE. It presents longitude and latitude angle measurements in whole degrees and decimal minutes. The decimal minutes are displayed to a resolution of two digits to the right of the minutes decimal point. A typical measurement of latitude may be displayed as 35° 15.01'. Why not use seconds instead of decimal minutes? Because a number presented to the nearest 0.01 arc minutes is more precise than one presented to the nearest arc second.

0.01' equals 1/100 minutes. This is smaller than 1/60 minutes. If we were to display two digits for seconds, then our rightmost digit in the seconds would be describing an angle which is larger than the rightmost digit in the 15.01 minutes format. Thus, the engineers who designed the GPS receiver have presented the angle measurement in a format which displays a smaller angle with the same number of digits displayed. This format presents a higher angle resolution with fewer digits and thus can more closely represent the instrument's internally computed latitude or longitude. To achieve the same resolution by displaying arc seconds, you would need to provide an extra digit for fractional seconds (35° 15' 00.6") on the instrument's display which costs more to build.

Many GPS receivers can be programmed to display angles in a variety of units and formats. It is up to you, the scientist, to decide which best suits your needs. If we want the extra resolution without displaying and recording more digits, decimal degrees are preferable to minutes and seconds.

Arithmetic with Degrees and Minutes

We cannot easily add angles expressed in degrees and minutes. Although we can perform arithmetic operations with angles in units of degrees, minutes, and seconds, it is easier to convert all the angles to decimal degrees, perform the arithmetic, then convert the result back to the desired units.

What To Do and How To Do It

Adding Angles with Mixed Units

Make up several angle values expressed in degrees, in degrees and minutes, and in degrees and minutes and seconds. Have the students add these together. Some students may realize that exceeding 60 minutes or seconds is similar to the "carry" when ten is exceeded in a column during addition.

Averaging Angles Measured in Degrees and Minutes

Background

The GPS protocol calls for averaging 15 latitudes and 15 longitudes. This smooths out the effects of slight variations over time in the values recorded. To average a series of numbers, you add them together then divide by the number of values added. Thus averaging calls for both addition and division. A series of 15 angles recorded in degrees and decimal minutes can be manipulated more easily if converted first to decimal degrees. Convert all 15 values, perform the addition and division, then convert the result back to degrees and decimal minutes.

When working with latitude and longitude values, retain five digits to the right of the decimal point in your intermediate results to maintain the resolution provided by the 0.01 arc minute measurement resolution.

An Averaging Example

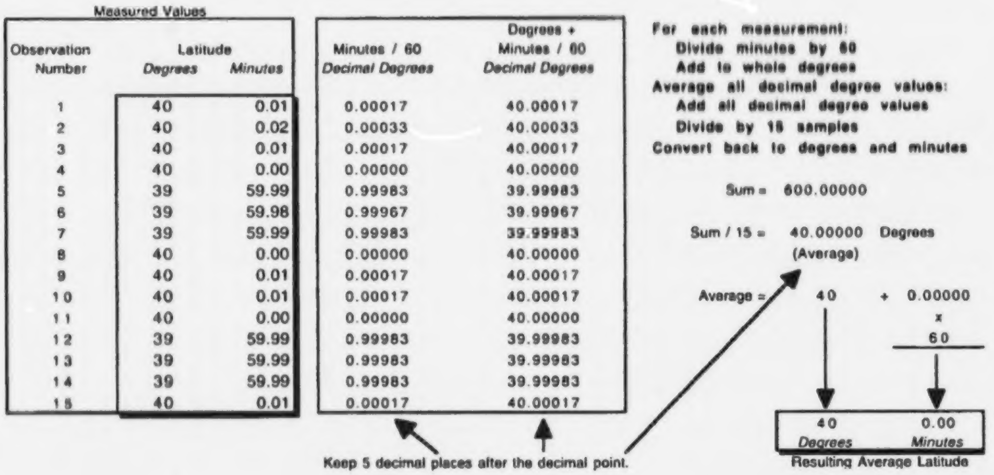
In the city of Boulder, Colorado, USA, there is an east-west street called Baseline Road. This east-west street lies on the 40 degree North line of latitude. If you were standing beside this street and recorded 15 GPS measurements, you might get the results listed below.

To produce an average, we convert each measurement from degrees and minutes to decimal degrees. We then add together all of these decimal numbers and divide by 15 to produce an average value of latitude in decimal degrees. Finally, we convert this decimal degree value back to a value with units of degrees and minutes.

What To Do and How To Do It

Again, make up a series of up to 15 angle values expressed in degrees and decimal minutes. The decimal minutes should be represented to the nearest 0.01 arc minute to correspond to the GPS receiver's displayed values. Have the students average these together by converting to decimal degrees, adding, dividing, then converting back

Figure GPS-L-21



Measured Values

Observation Number	Latitude Degrees	Latitude Minutes	Minutes / 60 Decimal Degrees	Degrees + Minutes / 60 Decimal Degrees
1	40	0.01	0.00017	40.00017
2	40	0.02	0.00033	40.00033
3	40	0.01	0.00017	40.00017
4	40	0.00	0.00000	40.00000
5	39	59.99	0.99983	39.99983
6	39	59.98	0.99967	39.99967
7	39	59.99	0.99983	39.99983
8	40	0.00	0.00000	40.00000
9	40	0.01	0.00017	40.00017
10	40	0.01	0.00017	40.00017
11	40	0.00	0.00000	40.00000
12	39	59.99	0.99983	39.99983
13	39	59.99	0.99983	39.99983
14	39	59.99	0.99983	39.99983
15	40	0.01	0.00017	40.00017

Keep 5 decimal places after the decimal point.

For each measurement:
Divide minutes by 60
Add to whole degrees
Average all decimal degree values:
Add all decimal degree values
Divide by 15 samples
Convert back to degrees and minutes

Sum = 600.00000

Sum / 15 = 40.00000 Degrees (Average)

Average = 40 + 0.00000 x 60

40 *Degrees*	0.00 *Minutes*

Resulting Average Latitude

to degrees and decimal minutes. It may be wise to confirm the intermediate and final results before attempting this in class.

Telling Time with the Sun

Background

Because Earth turns once (360°) per day (24 hours), celestial objects (sun, moon, stars) appear to move through 15° per hour (= 360°/ 24 hours). Your fist with thumb extended held at arm's length appears to occupy about 15° for most people. See the GLOBE GPS Learning Activity: Relative and Absolute Directions, for a discussion of hand-width angular variation and an illustration. Thus, your extended hand provides a portable measure of one hour of the sun's (or moon's) passage though the sky. By measuring the number of hand-widths from the sun to the western horizon, you can determine the number of hours until sunset. If you know the time of sunset, you can estimate the present time without a clock!

What To Do and How To Do It

Determine your local the time of sunrise and sunset. (See your newspaper.) Determine the location of the eastern and western points of sunrise and sunset as seen from your school.

Have your students go outside, measure, and record the distance in hand-widths from the sun to the closer rising or setting horizon. This produces best results early or late in the day when the sun is closer to its horizon. Warn the students to not stare into the sun, and record the time at which your class made its measurements.

The number of hand-widths should approximate the number of hours since the sun left or until the sun arrives at your horizon. Each student should add this to the sunrise or subtract this from the sunset time to get his estimate of the time of day. To produce a better time value, average all the hand-width values produced by your students. Use this value when determining the difference in hours between sunrise or sunset. After individual and group computations, announce the time recorded from the clock and discuss results. See GLOBE GPS Learning Activity *What is the Right Answer?*

Adaptations for Younger and Older Students

Younger students may round both the time of day and hand-widths to the nearest hour so that they need deal only with whole numbers which can be counted up or down. Older students may wish to attempt to increase their accuracy by being careful to determine closely the point on the horizon where the sun rises or sets, experimentally determining the angular size particular to their individual hand, including fractions of hand-widths, and converting to chronological minutes and hours. This technique can work surprisingly well!

Celestial Navigation

Purpose

Determine the latitude and longitude of another site by measuring each site's sun angles at solar noon

Overview

Your students make friends with students at another school at least 500 km distant. Both agree to make sun angle measurements on the same day at each school's local solar noon at a site of known latitude and longitude. Times and measurements are shared. Each school computes the latitude and longitude of the other school. Results are swapped and compared.

Time

4 class periods

Overview, local solar noon estimation, UT, setting clocks, plan

Build clinometer, install vertical pole, check for horizontal surface

Perform measurement

Computations, discussion, comparison with other school

Level

Intermediate and Advanced

Key Concepts

Time and sun angle measurements can be used to determine the differences in latitude and longitude between two locations.

Skills

Measuring an angle:
  using the clinometer *(intermediate)*
  using trigonometry *(advanced)*
Setting a clock accurately
Converting between local and universal time
Using a compass to determine north and south
Adding and subtracting angles
Multiplying and dividing (advanced)
Applying the tangent trigonometric function

Materials and Tools

An outdoors location with a flat surface and sunny view at solar noon
A pole which can be mounted vertically on a flat surface
A tape measure or ruler long enough to measure the pole's height and its shadow's shortest length with millimeter resolution
A clock set to local time
A magnetic compass or a rough knowledge of the north/south directions
Clinometer *(intermediate)*
A trigonometric arc tangent table or scientific calculator *(advanced)*
A globe or world map
Work Sheets
Computer and GLOBE Student Server

Preparation

Determine your site's latitude and longitude.

Make arrangements with another school for same day measurements.

Build and test the Land Cover/Biology clinometer.

Set a clock to local time.

Estimate the approximate time of local solar noon.

Prerequisites

Working with Angles

Background

In ancient times, Eratosthenes inferred Earth's circumference without having to walk all the way around our planet. He used geometry and a set of angle measurements of our sun taken in the two Egyptian cities of Syene and Alexandria which are separated by about 900 km. From this, he inferred Earth's circumference to be about 44,055 km. Although this is 15 percent larger than the actual 40,074 km, his result is an amazing demonstration of geometry and logic given the available measurement skills.

We now know Earth's dimensions quite well. Using our GPS receiver or a map, we can learn our own latitude and longitude. Can we use techniques similar to those of Eratosthenes to determine another school's latitude and longitude?

Yes. We can measure the angles of our sun at both our and another school to determine our differences in latitude. The difference between the two times of our sun's highest angle at each school tells us our difference in longitudes. The time when our sun is highest in the sky is called local solar noon and determines the time at which *Atmosphere Investigation* measurements are made.

Intermediate students can measure angles directly by constructing a clinometer as described in the *Land Cover/Biology Investigation*. Advanced students can infer angles by measuring the height of a pole and the length of its shadow using trigonometric techniques which tend to be more accurate than our clinometer measurement.

Before making any measurements, you need to become partners with another Globe school at least 500 km distant and plan a date on which you both can make outdoor measurements. You may use GLOBEMail to do this. You also need to determine your school's latitude and longitude by doing the *GPS Protocol*, to become familiar with the angles which describe latitude and longitude, and to be able to accurately set a clock to your local time-of-day.

What to Do and How to Do It

You and a partner school will:

Choose a date on which you both will make outdoor measurements

Estimate your time of local solar noon for the date of your outdoor measurements

Accurately set a clock

Perform outdoor sun shadow measurements

Swap measurement data between schools

Compute the latitude and longitude of the other school

Compare results

Outdoor Measurements

On the same calendar date, at each school's local solar noon, and from a site of known latitude and longitude, each school will record on the GPS Celestial Navigation Measurement Recording Work Sheet in the appendix of this activity:

height of a vertical pole

direction (north or south) of the pole's shadow

For twenty minutes before and after estimated local solar noon, each school will record at four minute intervals:

shadow length on flat ground from the vertical pole

(Intermediate only) angle between the horizontal ground and a line to our sun

You can estimate the time of local solar noon by following the procedure outlined in the *Atmosphere Investigation* or by a rough performance of this experiment within the previous week.

Figure GPS-L-22: Students Making Measurements

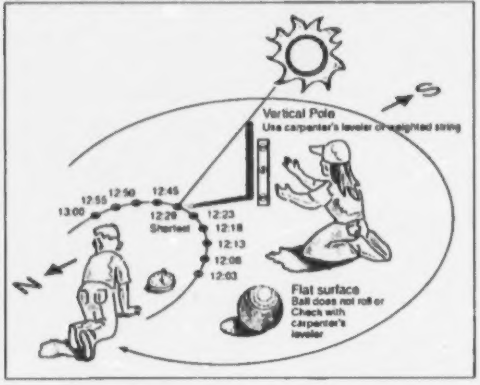
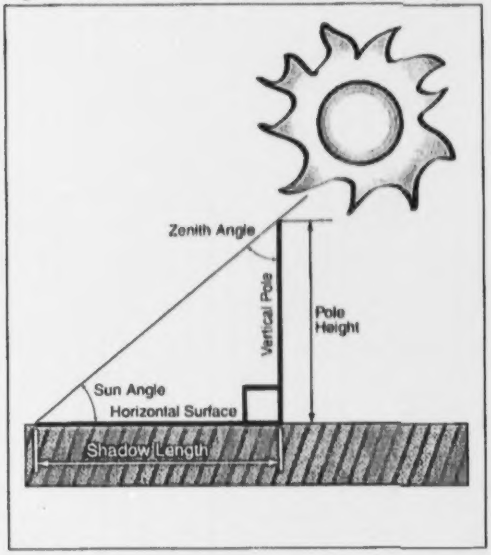


Figure GPS-L-23: Sun Angle, Vertical Pole, Horizontal Surface


Zenith Angle
Vertical Pole
Pole Height
Sun Angle
Horizontal Surface
Shadow Length

Measure the horizontal lengths in millimeters and sun angles in degrees of the shadows from a vertical pole at four minute intervals for twenty minutes before and after estimated local solar noon. Several people are needed to make these measurements:

(*Intermediate only*) One person should carefully hold and adjust the clinometer to keep it aligned with the sun by observing the spot of sunlight through the straw on his hand.

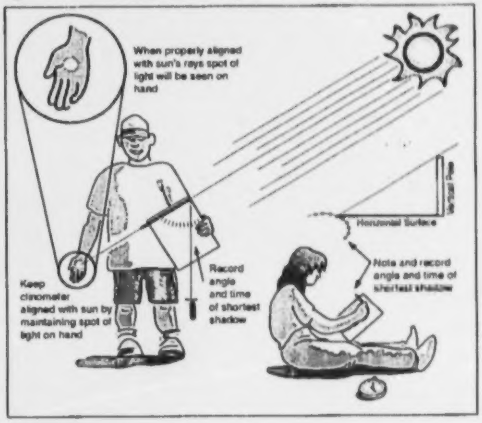
(*Intermediate only*) Someone else should observe the angle indicated on the clinometer. Use the clinometer to measure the angle from horizontal to our sun to the nearest degree. DANGER: Do not look through the clinometer at our sun! This will harm your eyes.

One person should measure and mark the lengths of a shadow from a nearby vertical pole.

A timekeeper with the Data Recording Work Sheet should observe the time of day. At four minute intervals during the experiment, he should ask the observer of the clinometer for his measured angle and the observer of the shadow for his measured length then record these values.

The clinometer described in the *Land Cover/Biology Investigation* uses a drinking straw for optical alignment. Do not try to look at our sun through the straw on your clinometer! You will harm your eyes. Instead, hold the clinometer with one hand. Align it so that you cans see a spot of sunlight through the straw in your other hand as shown in the illustration.

Figure GPS-L-24: Students Using Clinometer


When properly aligned with sun's rays spot of light will be seen on hand
Vertical Pole
Horizontal Surface
Keep clinometer aligned with sun by maintaining spot of light on hand
Record angle and time of shortest shadow
Note and record angle and time of shortest shadow

Swap Measurements with Your Partner School

Be sure to confirm that your partner school indeed was able to make the measurement on the same calendar day. If weather or other events precluded a successful measurement at either school, the pair of measurements should be repeated on another day. Why? Because the angle of our sun changes each day as the seasons change.

While you are welcome to swap all of your data, exchange at least your measurements of:

universal time of shortest shadow
shortest shadow length
(*intermediate*) sun angle at the time of the shortest shadow
pole height
pole's shadow direction (north or south)

Then each school computes the latitude and longitude of the other.

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Find Their Latitude

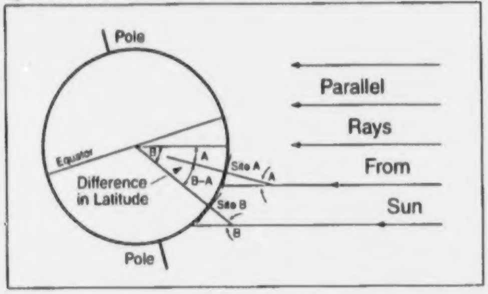
Our sun is roughly 150 million kilometers away and appears to us as a disk one-half a degree across. Because of this, for the purpose of this activity, we can assume that all the rays of light coming from our sun are parallel. Look at Figure GPS-L-25; on any given day at local solar noon, the angle at which these rays of light strike the Earth's surface varies with latitude alone. If we compare measurements of this angle made on the same day at two different places, we can determine the difference in latitude between these two places.

As Earth rotates on its axis, the angle at which sunlight strikes the surface varies, and so it is important that observations for two locations that are going to be compared be made at the same local solar time. At local solar noon, our sun is either directly overhead or the angle at which the light strikes the surface is oriented north-south and all the difference between two locations is due to variation in latitude. The angle at which sunlight strikes the surface also varies from day to day as Earth orbits our sun, and so measurements that are going to be compared must be made within one day of one another.

To find the latitude of another school, copy your and your partner school's measurements at local solar noon onto the GPS Celestial Navigation Latitude Calculation Work Sheet. Look at the example Work Sheet then perform the calculations as outlined on the blank Work Sheet and repeated here:

For each school's data:
(*Advanced*) Compute sun angle
(*Intermediate*) Use the measured sun angle
Compute the zenith angle (90 - sun angle) [degrees]
Compute latitude difference (subtract zenith angles)
Compute the difference in your latitudes
Compute the partner school's latitude

Figure GPS-L-25: Latitude Sun Angle Relationship



Determine your time of local solar noon from your measurements. This occurs when the shadow is the shortest. Because you may have several length measurements with the same short length, choose the time of the one closest to the center of your identically short length measurements. Convert this to universal time and record this on your calculation Work Sheet in addition to the other measured data from you and your partner school.

Follow the computations shown on the Work Sheet. Advanced students will determine our sun angle from a trigonometric computation whereas others will use angles measured with the clinometer.

We really need the Zenith Angle. This is the angle between a line pointing at our sun and a vertical line. It is the difference between our angle to our sun and our angle to the zenith. The zenith is defined as always being directly over our heads wherever we are. The vertical pole points to our zenith. Because the sum of all triangle internal angles is 180 degrees and we know that one of the angles is 90 degrees if the pole is vertical and the ground is horizontal (flat), then we can subtract 180 minus 90 minus our sun angle to get the zenith angle.

Why do we need the zenith angle? If our sun were directly over the equator (spring and fall equinoxes on about 21 March and 21 September), then our sun's rays would be parallel to our equator. Thus, the zenith angle would be the same as our latitude. Knowing our sun angle at another school would tell us their latitude. However, on days other then the equinoxes, our sun is not directly over our equator, so it's rays come down at different angles. But, both schools experience the same parallel rays from our sun on the same day regardless of location. So if we subtract what would be our latitudes on the days of the equinoxes, we also shall be canceling out the offset due to our sun's seasonal movements because this offset is experienced equally at both schools. Thus, on any day we can determine the difference in latitudes between schools. Knowing this difference and knowing our latitude (from perhaps a map or GPS receiver measurement) allows us to infer the latitude of the other school.

Corrections

Each school could be viewing our sun from different north-south directions. This can change throughout the year as our sun moves in its seasonal cycle. In this case, we might need to look for a sum instead of a difference between the school zenith angles. The relationship between the directions of the poles' shadows tells us whether we need a sum or difference between zenith angles. The Work Sheet has a table indicating conditions for summation or subtraction.

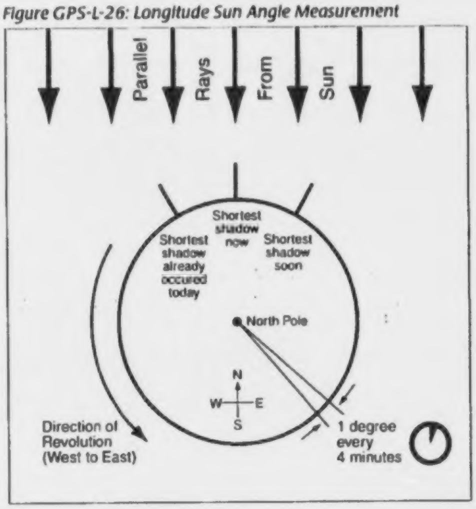
It is also possible that your partner school is in the hemisphere opposite yours. If so, you will get a negative latitude when you perform your final subtractions. In this case, just change hemispheres and make the result positive.

Find Their Longitude

Because we are on a planet which rotates one degree every four minutes, knowing the difference between the times of our and another school's local solar noon tells us about our longitude differences. Universal Time should be used by both schools so that we are working in a common reference frame. Perform the computations as outlined on the Work Sheet. See the example form then perform the calculations as outlined on the blank form and repeated here:

For each school's data:
Use Universal Time for local solar noon
Convert times into minutes into the day (UT)
Find the time difference in minutes between local solar noon at your and your partner's schools
Convert the time difference into a longitude difference (one degree every four minutes)
Add or subtract from your school's measured longitude
Correct for hemisphere changes
Compute the partner school's longitude

Figure GPS-L-26: Longitude Sun Angle Measurement



All these phrases describe the same thing:

24 hours in a day
24 hours for Earth to rotate once relative to our sun
24 hours in a 360 degree rotation of Earth
1440 minutes in a 360 degree rotation of Earth
4 minutes in a 1 degree rotation of Earth
4 minutes in a 1 degree east-west movement of our sun
every 4 minutes, Earth rotates through 1 degree of longitude

So every 4 minutes, our sun moves 1 degree.

Because we are on a planet which rotates one degree in every four minutes, knowing the difference between the times of our and another school's local solar noon tells us about our longitude difference. Universal Time should be used by both schools so that we are working in a common reference frame. Perform the computations as outlined on the Work Sheet.

Time is important for longitude computations. Contrast this with the latitude computations where angle measurement is important. Pendulum clocks were developed long before self-regulating spring driven clocks. But pendulums do not work well on a moving and tossing ship. Until the development of clocks which did not require pendulums, ships could determine their latitudes but not their longitudes. The epic struggle to develop a technology which solved this problem is outlined in the book *Longitude* (by Dava Sobel, 1995, Walker Publishing Company, NYC).

To facilitate not having to deal with fractions of hours, convert the UT time-of-day from hours and minutes into a number of minutes into the day for each school. Find the difference between these times to determine the amount of time between local solar noon at each site. Because Earth turns at a fixed one degree in every four minutes, divide the time difference by four to compute the angular longitude difference in degrees between schools.

Our planet rotates from west to east. You can remember this by recalling that the sun rises in the east which means that you must be traveling toward the sun and therefore moving to the east. Thus the school which experienced its local solar noon first is east of the other school. This tells you whether to add or subtract the differences in longitudes between schools to your longitude to get the other school's longitude.

Corrections

If the other school's longitude value is negative, then they are across the Prime Meridian (0 degrees Longitude) from you. In this case, change east-west hemispheres and use a positive longitude value. Should the value be greater than 180 degrees, then they are across the International Date Line. In this case, switch hemispheres, subtract 360 degrees, and take the positive value for their final longitude.

Compare with Your Partner School

Communicate with your partner school and share results. What happened? Did you compute their location? If not, how far away were you? Do you know why? Can you compare any error in your answer to that of Eratosthenes? Can you determine why?

Questions and Further Study

People have used celestial objects (stars and our sun and moon) for centuries to determine their location on Earth. How is this different from our activity? Imagine our other school residing at a latitude of zero degrees and a longitude of zero degrees and our having a table of sun angles for local solar noon at this school's location throughout a year. We could take sun angle measurements and determine the time of local solar noon at any site we choose then work the above problem backwards to determine our location anywhere in the world. This has been done for several hundred years and become progressively more accurate with the development of better clocks and angle measurement techniques. Mathematicians and astronomers develop the necessary tables from a knowledge of the spatial relationships between Earth and a variety of celestial objects. The Global Positioning System operates using similar principles with the exceptions of visible and natural celestial bodies being replaced with artificial satellites using radio signals

How can we accurately set our clocks?

How do we learn the correct time-of-day? Easily available sources which typically can give you the time to better than one second accuracy include:

the hour tone on a local radio or television station
various short-wave radio stations
Internet based time transfer software for computers
A GPS receiver

Broadcast Stations

Local television and radio stations need to coordinate their transmissions with other stations and their sources of information. Therefore, they are heavily motivated to know the time to better than the nearest second. Many commercial radio stations offer a tone at the "top of the hour" (zero minutes, zero seconds) to which one can set one's clock. Various international short-wave radio stations exist which broadcast only the time-of-day.

How long does it take for the signal to get from the radio station to you? If you are 100 km from the radio station when the tone occurs, the signal traveling at the speed of light (3.0×10^8 meters/second) will arrive at your radio one third of a millisecond (one millisecond = one thousandth of second) after it is sent. The sound from the radio will take 3 milliseconds to travel at the speed of sound (331 meters/second) from the radio to your ear if you are one meter from the radio. So any error in when you manually adjust the clock probably will be longer than the time it takes for the signal to get from the radio station to you.

Computer Networks

You can get the time from the US Navy via Internet at http://tycho.usno.navy.mil. Your computer's communications software breaks its digital data into packets which are shipped through the network via potentially different paths with unknown and varying delays. These packets also take some time to transmit. Therefore, we cannot easily know the time difference between when you see the time displayed and when the remote computer actually responded to your request.

Software exists for use via Internet which can transfer the time-of-day from another computer to yours. Some of this software is sufficiently sophisticated in that it can bounce messages between the two computers to measure, then average the time delay between the two computers. Once this delay is estimated, it can be added to the time which was sent from the remote computer to attempt to correct for the various network travel delays.

Astronomers sometimes use a slightly different time (sidereal time) which is synchronized to the motion of the stars. This differs by about 4 minutes per day from our "Civil Time" (the time-of-day typically indicated on our clocks) which is referenced to our relationship to our sun. Other sources of time available on the web include:

http://www.greenwich2000.com/time.htm
http://www.bldrdoc.gov/doc-tour/atomic_clock.html

Global Positioning System

GPS is an inherently time based system. Because your locations are inferred from time signals sent from satellites with onboard atomic clocks which are accurately set, your GPS receiver can display the time-of-day. More elaborate GPS receivers even compensate for the time it takes for the signal to travel from the satellite to your GPS receiver because it knows the distance to the satellite and thus can infer the delay (which is about 67 milliseconds).

Local Time versus Universal Time

In this activity, both your and the remote schools are going to find your time of local solar noon by recording your local time-of-day when our sun's shadow becomes shortest. You will then determine the time difference between local solar noon at both schools.

Because our sun appears overhead at different times at different longitudes, governing bodies decided to segregate our planet into 24 different time zones separated on average by 15 degrees in longitude which is the distance corresponding to one hour of Earth's rotation. Thus, it is quite possible that the time when our sun is highest in the sky (local solar noon) near your school is quite different from that of a far away school. Also, the other school may be in another time zone where all their clocks may be different from yours by one or more whole hours. However, we can have both schools present their time measurements in a common time reference. We then can subtract the two times to determine a difference.

For historical reasons, the time along the meridian through Greenwich, England is defined as Universal Time. We change our local time to Universal Time by adding or subtracting a whole number of hours which depends on our location.

We can determine the number of hours to add or subtract for our conversion to Universal Time by looking at a map or globe which indicates time zones or asking someone who knows. This may change by the local application of Daylight Savings Time. The work of aviation and weather officials typically requires their knowledge of local time standards. Most GPS receivers can be set to display either local or universal time.

See for links to web pages displaying Universal Time.

How accurate are our results?

How close (in degrees) are your computed latitude and longitude from those measured at the other school's site? What affects this difference? Assuming that you perform the arithmetic correctly and the formulas used are correct, poor results could come from instrumentation errors in the measured data which includes:

Size of fuzzy shadow
Alignment of tube
Ground not flat or pole not vertical
Determination of time of local solar noon

How can you determine which error sources cause more trouble? Pretend to perform the experiment. Make up a set of measurement numbers that you would expect to get under ideal circumstances. Perform the calculations on your ideal numbers and make sure that you get the ideal answer that you expect. Then make up a set of numbers which are all ideal except for a single error. Choose the error value to be typical of what you might observe. For example, you might add a few millimeters to the shadow length, whereas, adding 100 meters clearly is too much. Perform the calculations on these numbers and compare to the ideal results.

When you do this, you are performing a simulation to test your experiment's sensitivity to each of the error sources. For complex experiments with a large number of measurements and a lot of equations, a computer program may be used to vary all of the identified sources of error to determine the various extremes in outcomes.

Does it matter if the pole is vertical? How can we confirm that the pole is vertical?

You can use a carpenter's level to confirm that your pole is vertical. It is possible for the pole to be vertical in a north-south plane but not in an east-west plane. So be sure to try the level on several sides of the pole to make sure that it is completely vertical.

A vertical line is formed by a string supporting a weight. If your pole happens to be a piece of pipe, then you can test your pipe by lowering a weight into the pipe. When you orient the pipe so that the string is centered along its entire length, then the pole is vertical. The weight is sometime called a "plumb bob" because the weights used to be made of lead. A former chemical name for lead was "plumbum" from which comes the English word "plumber".

Some folks do not even use a pole when performing this measurement. They just hang a string with a weight from some overhead object. The string must have a knot or some other object big enough to cast a visible shadow and should be attached about 1/2 to 1 meter above the flat surface. The distance from the surface to the knot is measured carefully and recorded as the vertical distance. However, this technique has problems if the wind blows the string and weight.

Errors will be introduced into the trigonometric angle measurement technique if the pole is not vertical and your surface is not flat. This is not a problem for the clinometer technique for measuring our sun angle, however, it increases the difficulty of determining the minimum shadow length.

Does it matter if the ground is flat? How can we confirm that the ground is flat (horizontal)?

If a soccer or other ball will roll away, your surface is not flat. More sensitive techniques use the tendency of liquids to move to their lowest possible point. You can use a carpenter's level to confirm that your surface is flat. Be sure to place the level so that the tubes containing the liquid are parallel to your surface.

A drop of water on a surface will form a ball and cling to the surface even if it is not exactly horizontal. Detergents are chemicals which reduce the surface tension of a liquid. Gently drop a slight amount of a domestic powered detergent into a small amount of water on a surface. This should reduce the surface tension of the water sufficiently so that it will flow downhill if the surface is not flat. This can assist you both in determining if your surface is flat and correcting it if you can move it.

A more sophisticated technique for determining a common horizontal plane uses a long flexible and transparent tube almost completely filled with a liquid. Two students, each holding one end of the tube, move far apart holding their ends of the tube up so not to spill the liquid. Regardless of their distance, the levels of the liquids at each end will be the same.

Geologists use a variation of this technique to detect slight upheavals or drops in our planet's surface. They bury or lay on the ground a horizontal pipe which may be hundreds of meters long and fill this pipe half full of water. The pipe is adjusted up and down until a half full pipe is observed at each end. Should the ground move slightly producing an angular change of even a fraction of a degree, the water will move to one end of the pipe. This is an example of building a sensitive instrument which indicates a slight difference with a dramatic change. You can do the same with a long transparent tube of moderate diameter.

Errors will be introduced into the trigonometric angle measurement technique if the pole is not vertical and your surface is not flat. This is not a problem for the clinometer technique for measuring the sun angle, however, it increases the difficulty of determining the minimum shadow length.

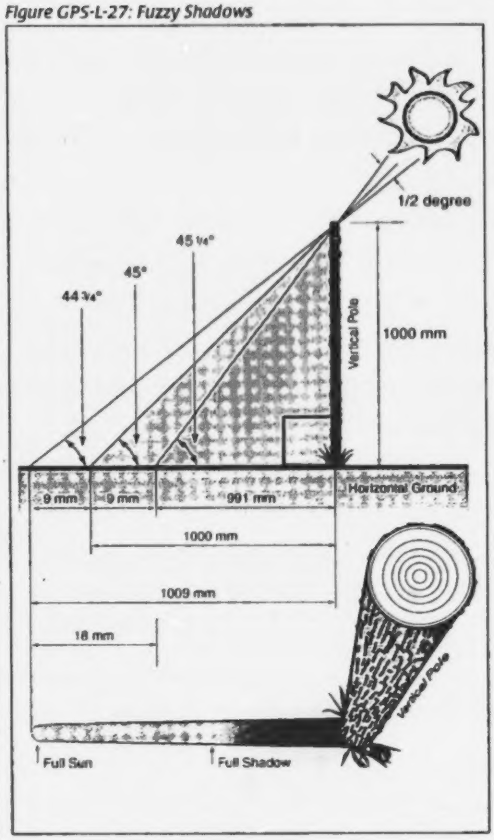
What if we get a fuzzy shadow?

If you are on Earth using our sun as a light source, you should always get a fuzzy shadow. With a short pole, you might not notice the softness of the shadow's edge, but no shadows from our sun have sharp edges on Earth.

Why? Because the light from our sun does not appear to come from a point source. Instead, it appears to come almost uniformly from a circle about one half of a degree across (which presently is about the same angular size as our moon thus making our total solar eclipses so interesting).

Because it would harm your eyes to look directly at our sun, look at the full moon some night. Light radiates towards you from the center, top, bottom, right, and left sides of the moon. All this light is approaching you or any object which can cast a shadow from slightly different angles

Figure GPS-L-27: Fuzzy Shadows



For example, if a one meter tall vertical pole was located where our sun appears to be 45 degrees up in the sky, the light rays which pass immediately above the top of the pole are coming from slightly different parts of our sun. The rays from the center may be coming down at a 45 degree angle but the rays from the top will be coming down over the top of the pole at an angle one quarter of a degree steeper ($45 + 0.25 = 45.25$ degrees). Conversely, the rays from the bottom will be approach at a quarter degree more shallow angle ($45 - 0.25 = 44.75$ degrees). The shallower rays will land further away from the pole (1009 millimeters) while the steeper rays will be closer up to (911 millimeters). This is a 18 millimeter (almost 2 centimeter) difference between the edge of the full sunlight area and the full shadow area.

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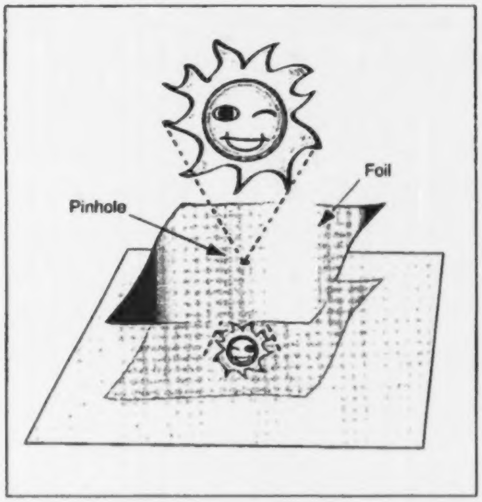
For measurement purposes, this is a problem. One could begin measuring at the edge of the full sunlight or the edge of complete shadow. But because the light gradually fades from full sunlight to full shadow, there is no distinct edge. Because it produces almost the desired angle, try to estimate the middle of the light to dark area and use this as your distance.

In the above example, if one were to use the lighter or the darker edge instead of the shadow's middle, this could induce an error of a quarter degree either way. This becomes an error of about 26 kilometers when converted to a difference in latitude.

This is not a problem with stars. Although they are quite large, they are so far away that they appear to be less than one arc second across. Thus for navigation purposes they appear to be points. Also, the top or bottom edges of our sun may be used. Instruments used for making these angle measurements with celestial bodies are called sextants.

GPS-L-28: Pinhole Camera


Foil
Pinhole

One can see a picture of our sun by making a pinhole camera. Use a pin to form a small hole in a piece of aluminum foil. If you hold this up to our sun over a flat, light colored surface, you can see an inverted image of our sun projected on the surface. This is a good way to view sunspots or a solar eclipse.

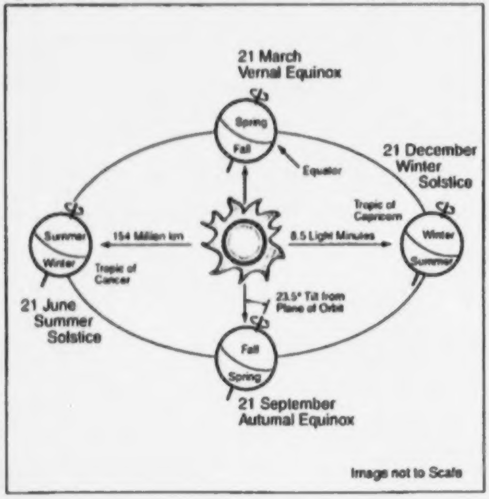
Occasionally the arrangement of leaves in trees above us form small holes through which sunlight shines to cover the ground with circles of light. During a solar eclipse, you can see the ground covered with the projections of the arcs of the uncovered sun. If you are under heavy canopy at night so that your eyes have adapted to the dark when there is less than a full moon, you can see clear images of the partial moon projected on the ground through small gaps in the leaves.

Why not use a single sun angle measurement to determine our latitude?

Earth orbits from west to east at an average distance of about 150 million kilometers from our sun. However, our planet's spin axis is tilted about 23.5 degrees out of the plane of its orbit. Therefore, on one side of our orbit, the northern hemisphere experiences sunlight closer to perpendicular over a larger area than does the southern hemisphere. This is the northern hemisphere's summer and the southern hemisphere's winter. The seasons swap for the hemispheres as our planet moves to the other side of our sun. A terrestrial observer sees the sun at a higher angle in his sky during his summer.

Several geographic and astronomical definitions are a consequence of this tilt. The Arctic and Antarctic Circles are defined as being about 23.5 degrees away from the north and south poles

Figure GPS-L-29: Sun-Earth Seasonal Relationships


21 March
Vernal Equinox
Spring
Fall
Equator
21 December
Winter
Solstice
Tropic of Capricorn
Winter
Summer
154 Million km
8.5 Light Minutes
Summer
Winter
Tropic of Cancer
21 June
Summer
Solstice
23.5° Tilt from Plane of Orbit
Fall
Spring
21 September
Autumal Equinox
Image not to Scale

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respectively. These are the lowest latitudes which can experience total darkness in their respective winters. The Tropic of Cancer and Tropic of Capricorn are defined as being 23.5 degrees north and south respectively of the equator. These are the latitudes farthest from the equator which ever experience our sun directly overhead. In the northern hemisphere, the yearly date of the highest sun angle usually occurs on 21 June. In the southern hemisphere, this occurs on 21 December. These days are defined as being the summer and winter solstices respectively in the northern hemisphere. Our sun appears to be directly overhead at the equator on about 21 March and 21 September. These are defined as being the vernal and autumnal equinoxes.

From any point on Earth, the angle of the sun appears to change daily with a year long cycle attached to the seasons. So if you were to make a sun angle measurement one day and your partner school were to do so on another, you would have an angle difference between your schools which is due to both different latitudes and different sun angles. However, in any 24 hour period, our sun's seasonal motion is less than a single degree.

How high would the sun appear in the sky during summer and winter for various places on Earth? On the equator? The north pole? Where you live? Astronomers developed equations which model the motion of celestial bodies. Computer programs exist which use these equations to compute the positions of our sun, moon, and other celestial bodies as seen from anywhere in the world at any time.

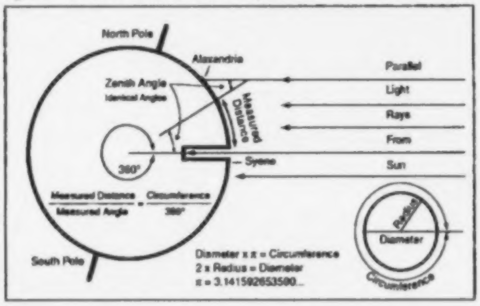
Sunlight falling perpendicular to the ground presents about 1000 watts of solar radiation to every square meter of brightly sunlit ground. Intuitively, this is the equivalent to 10 medium sized incandescent light bulbs falling on every square meter under our sun. And there are a lot of square meters on our planet. Contrast this to sunlight falling at 45 degrees which presents only about 700 watts to every square meter on an otherwise equally clear day. This difference in incoming solar radiation accounts for the accumulated energy differences between seasonal extremes which are indirectly observed as temperature changes.

How did Eratosthenes perform his experiment?

Eratosthenes was a Greek mathematician and scientist who lived during the 3rd century BC. He noticed that on one particular day in the year, sunlight could be seen reflecting from the water of a deep well in the city of Syene, Egypt. This meant that our sun was directly overhead in Syene. On this same day, the angle of our sun's shadow from a vertical pole was measured carefully in the northern port city of Alexandria, Egypt and found to be one 50th of a circle which is about 7.2 degrees.

Eratosthenes paid someone to walk due north from Syene to Alexandria who measured this distance to be 500 stades. A stade is about 185 meters or 607 feet. Because he walked due north, he was walking along a line of constant longitude with only his latitude changing.

Figure GPS-L-30: Eratosthenes' Experiment



Knowing the circumference distance and angular separation between two points on a circle allows us to infer the circumference of that circle. If we assume Earth is round (as did some ancients contrary to legend), we can deduce Earth's circumference from the above information. Eratosthenes did this resulting in a circumference estimate of 250,000 stades or 44,055 km. Today, we estimate Earth's circumference to average about 40074 km. Thus, Eratosthenes was in error by about 15 percent. Given the technology and scientific knowledge of the time, this is a remarkable deduction.

Techniques similar to these now used have been developed over centuries for land, sea, air, and

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space navigation. A sextant is a hand-held theodolite which is used to make angle observations of celestial bodies for navigation purposes. It is just a higher accuracy version of our clinometer. When done correctly, a hand-held sextant, clock, and computation tables can be used to determine your location to within two kilometers worldwide. For details, see annually updated navigation book *The American Practical Navigator: An Epitome of Navigation,* Nathaniel Bowditch, US Defense Mapping Agency, Bethesda, Maryland, 1st Edition 1802.

Students can explore the World Wide Web for information on Eratosthenes.

Other Questions

Did our measured data make sense? Did the intermediate and final calculations and their results make sense? If not, can we determine why?

Compute what the other school would believe to be our location.

How would shadow lengths behave at a planet's poles? (Same length all day.)

What days will have the shortest and longest shadows?

Should we see much east-west movement in the shadow? A little. During the 40 minute interval around noon, should we see much change in the shadow's length or sun's angle? Very little? But if you have time, measure and record what happens over several hours.

Figure G PS-L-31: An Example Celestial Navigation Measurement Recording Work Sheet

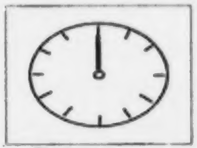
GPS Celestial Navigation

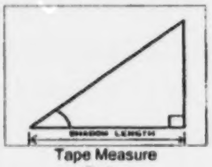
Measurement Recording Work Sheet

NAME *Jordan Malik*
DATE *April 19th 1994*

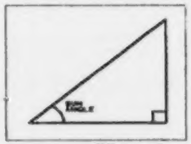
Record for the Period of 20 Minutes before and after Estimated Local Noon

Direction of Shadow
(circle one)
[✓ North] or South


Clock

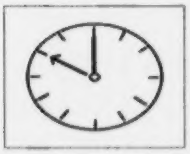


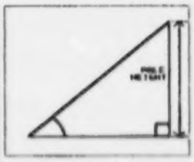
Tape Measure
Ruler



Clinometer
(Intermediate Only)

	Difference from Local Noon [minutes]	Local Time-of-Day [HH:MM]	Shadow Length [mm]	Sun Angle [degrees]
Before Local Noon	-20	11:52	454	65
	-16	11:56	451	66
	-12	12:00	448	66
	-8	12:04	446	66
	-4	12:08	446	66
Estimated Local Noon	0	12:12	445	66
	4	12:16	446	66
	8	12:20	447	66
	12	12:24	449	66
	16	12:28	451	66
After Local Noon	20	12:32	455	65





(Advanced Only)

Pole Height [mm]: *1000*

GPS Celestial Navigation

Measurement Recording Work Sheet

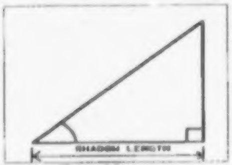
NAME ____________________

DATE ____________________

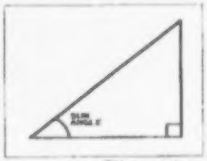
Record for the Period of 20 Minutes before and after Estimated Local Noon

Direction of Shadow
(circle one)
North or South

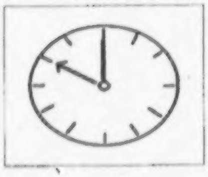
Clock



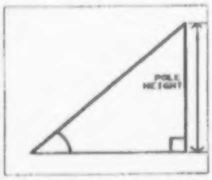
Tape Measure
Ruler



Clinometer
(Intermediate Only)



	Difference from Local Noon [minutes]	**Local Time-of-Day** [HH:MM]	**Shadow Length** [mm]	**Sun Angle** [degrees]
Before Local Noon	-20			
	-16			
	-12			
	-8			
	-4			
Estimated Local Noon	0			
	4			
	8			
	12			
	16			
After Local Noon	20			



(Advanced Only)

Pole Height
[mm]

Figure GPS-L-32: An Example Celestial Navigation Latitude Calculation Work Sheet

GPS Celestial Navigation

Latitude Calculation Work Sheet

NAME *Jordan Malik*

DATE *April 19th 1994*

		Our School		Their School	
Measurement Data	Our Latitude	35.3	[Degrees]	We are going to compute theirs	
	Our Longitude	78	[Degrees]		
	Universal Time of Minimum Shadow Length	17:12	[HH:MM]	17:37	[HH:MM]
	Length of Shadow at Minimum Length Time	445	[mm]	411	[mm]
(Intermediate)	Sun Angle at Minimum Length Time	66	[Degrees]	not given	[Degrees]
(Advanced)	Height of Pole	1000	[mm]	1000	[mm]
	Direction of Pole's Shadow	[✓ North] or South		[✓ North] or South	

Compute Sun Angle

Computed Sun Angle = arc tangent (Pole Height[mm] / Shadow Length[mm])

(Advanced Only) Computed Sun Angle = 66 [Degrees] 67.5 [Degrees]

Advanced students should use the computed Sun Angle throughout computations

Compute Zenith Angle This is the angle at the top of the triangle.

If the sun were over the equator when you made your measurements, then the Zenith Angle would be your latitude.

Zenith Angle = 90 [degrees] - Sun Angle [degrees]

Our Zenith Angle 24 [Degrees] Their Zenith Angle 22.5 [Degrees]

Compute Latitude Difference

Because both Sun Angle measurements are made on the same day regardless of the sun's location, the difference in Zenith Angles gives us latitude change between schools.

1.5 [degrees] = Latitude Change = Our Zenith Angle 24 [degrees] + / - Their Zenith Angle 22.5 [degrees]

(If a negative result, keep only the positive magnitude)

If shadows point in different directions +

If shadows point in same direction -

Compute Their Latitude

33.8 [degrees] = Their Latitude = Our Latitude 35.3 [degrees] + / - Latitude Change 1.5 [degrees]

Different shadow directions -

Same shadow directions and:

Our sun angle is smaller -

Their sun angle is smaller +

Corrected Latitude

Their Latitude = 33.8 [degrees] [✓ North] or South (circle one)

If negative, then their school is in your opposite hemisphere

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GPS Celestial Navigation

Latitude Calculation Work Sheet

NAME ______________________ *DATE* ______________

		Our School	Their School
Measurement Data	Our Latitude	[Degrees]	We are going to compute theirs
	Our Longitude	[Degrees]	
	Universal Time of Minimum Shadow Length	[HH:MM]	[HH:MM]
	Length of Shadow at Minimum Length Time	[mm]	[mm]
(Intermediate)	Sun Angle at Minimum Length Time	[Degrees]	[Degrees]
(Advanced)	Height of Pole	[mm]	[mm]
	Direction of Pole's Shadow	North or South	North or South

Compute Sun Angle

Computed Sun Angle = arc tangent (Pole Height[mm] / Shadow Length[mm])

(Advanced Only) Computed Sun Angle = [Degrees] [Degrees]

Advanced students should use the computed Sun Angle throughout computations

Compute Zenith Angle This is the angle at the top of the triangle.
If the sun were over the equator when you made your measurements, then the Zenith Angle would be your latitude.

Zenith Angle = 90 [degrees] - Sun Angle [degrees]

Our Zenith Angle [Degrees] Their Zenith Angle [Degrees]

Compute Latitude Difference Because both Sun Angle measurements are made on the same day regardless of the sun's location, the difference in Zenith Angles gives us latitude change between schools.

[degrees] = Latitude Change = Our Zenith Angle [degrees] + / - Their Zenith Angle [degrees]

(If a negative result, keep only the positive magnitude)

If shadows point in different directions +
If shadows point in same direction -

Compute Their Latitude

[degrees] = Their Latitude = Our Latitude [degrees] + / - Latitude Change [degrees]

Different shadow directions -
Same shadow directions and:
Our sun angle is smaller -
Their sun angle is smaller +

Corrected Latitude
Their Latitude = [degrees] North or South (circle one)

If negative, then their school is in your opposite hemisphere

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Figure GPS-L-33: An Example Celestial Navigation Longitude Calculation Work Sheet

GPS Celestial Navigation

Longitude Calculation Work Sheet

NAME *Jordan Malik* DATE *April 19th 1994*

		Our School		Their School	
Measurement Data	Our Latitude	35.3	[Degrees]	We are going to compute theirs	
	Our Longitude	78	[Degrees]		
	Universal Time of Minimum Shadow Length	17:12	[HH:MM]	17:37	[HH:MM]
	Length of Shadow at Minimum Length Time	445	[mm]	411	[mm]
(Intermediate)	Sun Angle at Minimum Length Time	66	[Degrees]	not given	[Degrees]
(Advanced)	Height of Pole	1000	[mm]	1000	[mm]
	Direction of Pole's Shadow	[✓ North] or South		[✓ North] or South	

		Ours		Theirs	
Time	Universal Time of Minimum Shadow Length	17:12	[HH:MM]	17:37	[HH:MM]
	Convert into Minutes into the day = Hours x 60 + minutes	1032	[Minutes]	1057	[Minutes]

25 [Minutes] = Time Difference = 1032 [Minutes] - 1057 [Minutes]

(If a negative result, keep only the positive magnitude)

Compute Their Longitude

6.3 [degrees] = Longitude Difference = Time Difference 25 [Minutes] / 4 [minutes per one degree Earth rotation]

84.3 [degrees] = Their Longitude = Our Longitude 78 [degrees] + / - Longitude Difference 6.3 [degrees]

If we are in Eastern Hemisphere and
If our shadow is shorter earlier -
If our shadow is shorter later +

If we are in Western Hemisphere and
If our shadow is shorter earlier +
If our shadow is shorter later -

Corrected Longitude

If their longitude is < 0 degrees, then they are across the Prime Meridian (make the result positive and in your opposite hemisphere).

If their longitude is > 180 degrees, then they are across the International Date Line (subtract 360 degrees, make positive, and in your opposite hemisphere).

Their Longitude = 84.3 [degrees] East or [✓ West]

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GPS Celestial Navigation
Longitude Calculation Work Sheet

NAME ______________________ DATE ______________ *rev 6*

		Our School		Their School	
Measurement Data	Our Latitude	☐	[Degrees]	We are going to compute theirs	
	Our Longitude	☐	[Degrees]		
	Universal Time of Minimum Shadow Length	☐	[HH:MM]	☐	[HH:MM]
	Length of Shadow at Minimum Length Time	☐	[mm]	☐	[mm]
(Intermediate)	Sun Angle at Minimum Length Time	☐	[Degrees]	☐	[Degrees]
(Advanced)	Height of Pole	☐	[mm]	☐	[mm]
	Direction of Pole's Shadow	North or South		North or South	

Time

	Ours		Theirs	
Universal Time of Minimum Shadow Length	☐	[HH:MM]	☐	[HH:MM]
Convert into Minutes into the day = Hours x 60 + minutes	☐	[Minutes]	☐	[Minutes]

☐ [Minutes] = Time Difference = ☐ [Minutes] - ☐ [Minutes]

(If a negative result, keep only the positive magnitude)

Compute Their Longitude

☐ [degrees] = Longitude Difference = Time Difference ☐ [Minutes] / 4 (minutes per one degree Earth rotation)

☐ [degrees] = Their Longitude = Our Longitude ☐ [degrees] + / - Longitude Difference ☐ [degrees]

If we are in Eastern Hemisphere and
If our shadow is shorter earlier -
If our shadow is shorter later +

If we are in Western Hemisphere and
If our shadow is shorter earlier +
If our shadow is shorter later -

Corrected Longitude

If their longitude is < 0 degrees, then they are across the Prime Meridian (make the result positive and in your opposite hemisphere).

If their longitude is > 180 degrees, then they are across the International Date Line (subtract 360 degrees, make positive, and in your opposite hemisphere).

Their Longitude = ☐ [degrees] East or West

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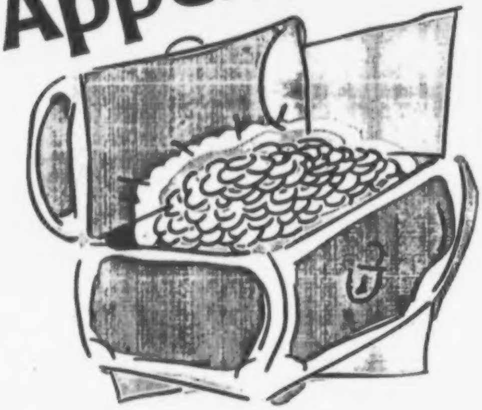
Appendix



GPS Investigation Data Work Sheet

Offset Data Work Sheet

Glossary

GLOBE Web Data Entry Sheets

GPS Investigation

Data Work Sheet

Site Name: ______________________

School Name: ______________________

School Address: ______________________

____

Data Recorded By: ______________________

Date Recorded: Year _____ Month _____ Day _____

Circle Site: Biology Land Cover Hydrology Atmosphere Soil Moisture

Soil Characterization School or another site: ____________

Wait at least one minute between recording observations.
Record the following from a Magellan Trailblazer XL's "Location 1" screen.

OBS	LATITUDE Degrees Minutes N/S	LONGITUDE Degrees Minutes W/E	ELEVATION Meters	TIME H:M:S UT	#SATs Satellites	Message Icons Circle If Shown
1	*33 46.55 N*	*84 23.84 W*	*318*	*14:33:00*	*4*	
1						☒ ◢ 2D ▣
2						☒ ◢ 2D ▣
3						☒ ◢ 2D ▣
4						☒ ◢ 2D ▣
5						☒ ◢ 2D ▣
6						☒ ◢ 2D ▣
7						☒ ◢ 2D ▣
8						☒ ◢ 2D ▣
9						☒ ◢ 2D ▣
10						☒ ◢ 2D ▣
11						☒ ◢ 2D ▣
12						☒ ◢ 2D ▣
13						☒ ◢ 2D ▣
14						☒ ◢ 2D ▣
15						☒ ◢ 2D ▣

Latitude	Longitude	Elevation	← Averages

GPS Receiver Provided by

UNAVCO/Globe ← OR → YOU

Magellan ______________ Manufacturer

Trailblazer XL ______________ Model Number

UNAVCO Sticker Number ______________ Serial Number

UNAVCO
(303) 497-8003
gretchen@unavco.ucar.edu
http://www.unavco.ucar.edu

GPS Investigation

Offset Data Work Sheet

Measurements

Circle One

From Offset Site:

Measured Latitude = ______ degrees ______ minutes N or S

Measured Longitude = ______ degrees ______ minutes W or E

To get to your site, go ______ (North or South)

Distance = ______ meters

Computations

Change in Latitude:

$$\frac{\text{\_\_\_\_\_\_ meters}}{\text{1855 meters/minute}} = \text{\_\_\_\_\_\_ minutes}$$

- If offset site further from Equator

+ If offset site closer to Equator

Your site's minutes of Latitude = ______ +/- ______ = ______

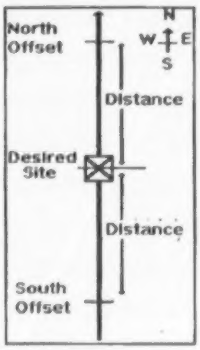
(Round to nearest 0.01 minutes) = ______ minutes

Combine with Latitude degrees:

Desired Latitude = ______ degrees ______ minutes N or S

Desired Longitude = ______ degrees ______ minutes W or E

(Same as Offset Longitude)



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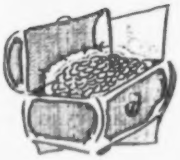
Glossary



accuracy

The difference between the indicated measurement value and the true value.

average

A technique for using one number to describe a group of numbers. An average (or mean) value is computed by summing a set of values and divided the sum by the number of values summed.

equinox

One of the two times of year when the sun appears directly over Earth's equator occurring typically on 21 March (vernal equinox) and 23 September (autumnal equinox). On these days, the times of daylight and night will be equal.

global positioning system (GPS)

The Global Positioning System is a navigation system that includes 24 satellites orbiting 20,200 kilometers above the Earth. Using time measurements of GPS satellite signals, the receivers can pinpoint our latitude, longitude, and elevation.

histogram

A frequency distribution plot indicating how often a particular number appears in a group of numbers.

latitude

The angle measurement in degrees of a planet north and south of its equator. Beginning at the Earth's equator (0°), latitude is measured in degrees, with the poles being 90° north and south.

longitude

The angle measurement in degrees east and west around a planet's spin axis. On Earth, the Prime Meridian is the north-south line through the town of Greenwich, England. This is 0° longitude, and the International Date Line is 180° from the Prime Meridian.

magnetic compass

A hand-held instrument displaying the angular orientation of a pivoting lightweight magnet. Because Earth behaves like a giant magnet, the magnet in the compass will point toward Earth's magnetic poles which generally indicates north and south.

magnetic variation

Also called Magnetic Declination, this is the angle between the magnetic and geographic (spin axis) poles specific to a locality. It is expressed in degrees east or west to indicate the direction to true north from magnetic north. Earth's magnetic north pole is slowly moving and presently located in Canada's North West Territories about 11 degrees away from our North Pole. Additionally, magnetic properties of Earth's composition vary slightly between locations contributing a unique distortion to Earth's magnetic field at any given site. Values may be found on navigation charts.

meridian

This is a circumference around the Earth's surface which passes through both poles and the equator. These form curves of constant longitude between any two poles.

navigation

The science and technology of determining course, position, and distance traveled.

offset site

This is a site directly north or south of a site where we are able to make a successful GPS measurement.

positions (or Locations)

Absolute

Measured from an agreed upon *fixed* location.

Relative

Measured from some arbitrary point such as your location.

plumb bob

A vertical line formed by a string supporting a weight. The weights used to be made of lead and a former and Latin derived chemical name for lead was "plumbum" from which comes the English word "plumber".

precision

The measure of the repeatability of an observation, that is if a measurement is repeated multiple times, how much will the individual measured values vary from the average of all the measurements.

resolution

The smallest change which can be *displayed* by an instrument.

satellite

Any celestial body that orbits another larger body.

solstice

One of the two times of the year when the overhead sun appears furthest from Earth's equator occurring typically on 21 June and 22 December. These will be the longest and shortest days of the year if your location is respectively closer to or further from the overhead sun.

sun angle

This is the angle between horizontal (the ground) and our sun. Sometimes this angle is called an elevation or altitude angle.

trigonometry

The mathematical study of triangles, trigonometric functions, and their applications. Trigonometric techniques allow us to relate angle values to the lengths of various sides of a triangle.

zenith angle

For our sun angle measurement, this is the angle between vertical (straight up) and our sun. In navigation, this is sometimes called a zenith distance. On the days of the spring or fall equinoxes, this angle will be our latitude. The zenith is the point directly overhead wherever we are. The sum of the sun angle and the zenith angle is 90°.

Circular Units, Distances, and Relationships

degree (°)

A circle may be divided into 360° (or 400 Grads or about two times Pi (Π Radians). Small fractions of a degree may be indicated either as decimal fractions (25.2525°) or using whole degrees, minutes, and seconds 25° 15' 9").

minute (arc minute, ')

One degree may be divided into 60 minutes. Therefore, there are 360 x 60 = 21,600 arc minutes (21.600') in a circle.

second (arc second, ")

One minute may be divided into 60 seconds. Therefore, there are 60 x 60 = 3600 arc seconds in one degree or 1,296,000 arc seconds (1,296,000") in a circle.

radian

An angle measurement unit equal to the angle subtended at the center of a circle by an arc equal in length to the radius of the circle. A full circle contains two times Pi radians or 360°. One radian is about 57.3°. For example: 25°. 15' 9" = 25.2525° = about 0.4407 radians. Pi is an irrational number (cannot be described as a ratio of two whole numbers and thus requires an infinite number of decimal digits) with a value of about 3.141592653590. Pi has been computed to millions of digits but the accuracy of the value listed here would induce errors of less than a meter when working with distances the size of our solar system.

Time Reference Frames

local solar noon

The time-of-day when the sun angle is greatest at your location. This time is specific to your location and varies by about a half-hour throughout the year.

mean time

Formerly called Civil Time, this is the time-of-day value typically displayed on our clocks. It is defined to cause the yearly *average* location of the sun to be the same and near overhead at noon in your time zone. Each time zone is different by one hour from adjacent time zones and is defined to be 15° of longitude with a few minor exceptions determined by governments to suit local needs or geography. Your mean may be related to Universal Time by determining your distance from Earth's 0° longitude either in 15° increments or numbers of time zones. Universal and Mean Time may be contrasted to Sidereal Time (used by astronomers and sometimes called star time) which is defined to bring distant celestial bodies to the same point in the sky after exactly one Earth rotation around its sun. A sidereal day is about 4 minutes shorter than a day as indicated using mean time.

universal time

Also known as UT, Zulu, or GMT (Greenwich Mean Time), this is the time-of-day for a 24 hour day defined to cause the yearly *average* location of the sun to be overhead at noon when observed at Earth's zero degree longitude.

Consequences of the 23.5° tilt of Earth's spin axis from the plane of Earth's solar orbit

Arctic and Antactic Circles

Also called North and South Polar Circles, these are the extremes in latitude (66.5° North and South) from Earth's poles where total darkness or sunlight may be experienced in local respective winters or summers.

Tropics of Cancer and Capricor

These are the extremes in latitude (23.5° North and South respectively) from Earth's equator between which the sun may be directly overhead at some time during the year.

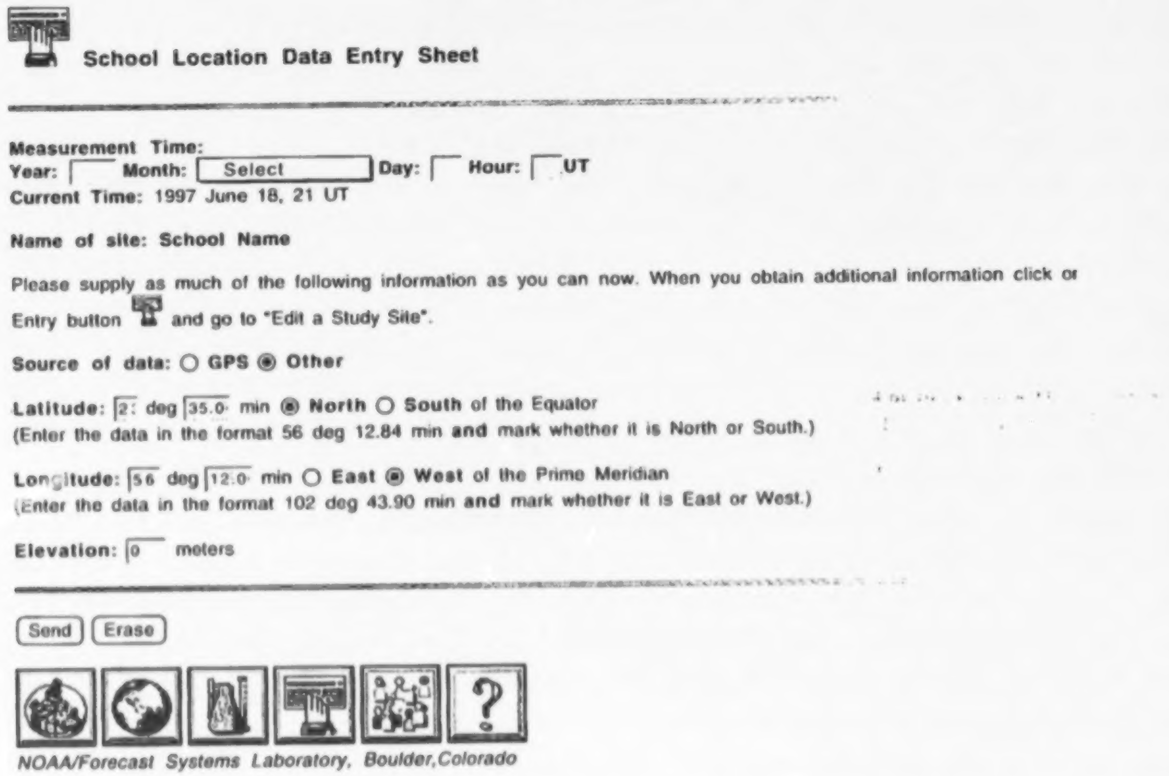
Define a Study Site

- Site for School Location
- Site for Temperature, Precipitation, and Cloud Observations
- Site for Surface Water Measurements
- Site for Soil Characterization
- Site for Soil Moisture
- Site for Biology Observations

To define the site for Land Cover Investigation click here to open Land Cover Quantitative or Land Cover Qualitative

NOAA/Forecast Systems Laboratory, Boulder,Colorado

GPS Investigation



School Location Data Entry Sheet

Measurement Time:
Year: ☐ **Month:** Select **Day:** ☐ **Hour:** ☐ **UT**
Current Time: 1997 June 18, 21 UT

Name of site: School Name

Please supply as much of the following information as you can now. When you obtain additional information click o Entry button and go to "Edit a Study Site".

Source of data: ○ **GPS** ● **Other**

Latitude: 2 deg 35.0 min ● **North** ○ **South** of the Equator
(Enter the data in the format 56 deg 12.84 min and mark whether it is North or South.)

Longitude: 56 deg 12.0 min ○ **East** ● **West** of the Prime Meridian
(Enter the data in the format 102 deg 43.90 min and mark whether it is East or West.)

Elevation: 0 meters

NOAA/Forecast Systems Laboratory, Boulder,Colorado

U.S. Department of Education
Office of Educational Research and Improvement (OERI)
National Library of Education (NLE)
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